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Volume 1: Techniques

GCA Corp.
Bedford, MA

Prepared for

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Volume I: Techniques

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16. ABSTRACT

This report presents guidelines for the identification and evaluation of localized violations of carbon monoxide air quality standards in the vicinity of streets and highways. The guidelines are provided to facilitate the rapid and efficient review of CO conditions along existing roadway networks, without the need for extensive air quality monitoring, and are based upon the use of limited traffic data. Two stages of review are provided for. Preliminary screening, performed with simple nomographs included herein, simply identifies those locations with the potential to violate CO standards; no quantitative estimate of CO concentrations results from preliminary screening. Verification screening, using procedures and forms provided herein, allows for consideration of additional site-specific conditions and provides quantitative estimates of maximum CO concentrations. Both screening procedures are performed manually and are based upon the EPA Indirect Source Review Guidelines. Data collection procedures, computation techniques, and forms are recommended, and examples are provided.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Errata for EPA-450/3-78-033
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1. Pages 83-84. The abscissa is in "hundreds" of vehicles.

2. Pages 96-97. All references to Figure "7B" should be "7D."

3. Page 157-159. Replace all of Table 12 with the attached Table 12.

4. Page 180. Step 16 should be Step 17, Step 17 should be Step 18, Step 18 should be Step 19, and Step 19 should be Step 16.

5. Page 180-181. Correct the following steps in the work sheet to reflect corrected numerical values:

Step 13	1.15	1.15	1.15	1.15
Step 14a	3.6			
Step 14b	0.7			
Step 15	4.3			
Step 16	0.82	0.82	0.82	0.82
Step 17	0.0159			
Step 20	6.4	1.9	0.6	0.3
Step 21	9.2			
Step 22	13.5			
Step 23	9.5			
Step 24	2.9			
Step 25	12.4			
Step 26	10.8			

6. Page 183. Line 6, change 2.85 to 1.41. The equation given for C_{Ef} should read:

$$C_{Ef} = (0.78)(0.83) + (0.11)(1.41) + (0.06)(5.23) + (0.05)(0.6) = 1.15$$

In the numerical solution for $X_{f,\ main}$ and $X_{f,\ cross}$ the emission correction factor should be changed from 1.33 to 1.15, thus yielding concentration estimates of 3.6 mg/m^3 and 0.7 mg/m^3 respectively. The total concentration then, X_f, should be $3.6 + 0.7 = 4.3$ mg/m^3.

7. Page 184. First paragraph, the excess emissions correction factor should be 0.82.

The numerical solution for Q_e should be:

$$(0.02297)(0.82) - (0.00251)(1.15) = 0.0159$$

8. Page 185. All concentrations given are incorrect and corrections are here given by line number.

Line 1	9.2 mg/m^3
Line 3	$4.3 + 9.2 = 13.5$ mg/m^3
Line 4	13.5 mg/m^3
Line 6	9.5 mg/m^3, 9.5 mg/m^3
Line 9	12.4 mg/m^3
Line 10	12.4 mg/m^3, 10.8 ppm
Line 15	12.4 mg/m^3, 10.8 ppm

9. Page 14, point d., second line, "vehicle" is mispelled.

10. Page 44, third paragraph, second line, "and" should be "an."

11. Page 112, second paragraph, lines 10 and 11, "ration" should be "ratios."

12. Page 173, points (a) and (b) reference to Table 8 should be Table 9, and Figure 33 should be Figure 38.

13. Page 199. First line, "Hozworth^{21}" should be "Holzworth^{22}"

Assumption 4, last line, "mexiing" should be "mixing"

Last paragraph, third line, change "in assumption 5" to "above"

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Carbon Monoxide Hot Spot Guidelines

Volume I: Techniques

by

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Prepared for

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ABSTRACT

This report presents guidelines for the identification and evaluation of localized violations of carbon monoxide air quality standards (i.e., hot spots) in the vicinity of streets and highways. These guidelines facilitate the rapid and efficient review of carbon monoxide conditions associated with existing urban street systems without the need for extensive air quality monitoring. The procedures presented in the guidelines employ traffic and roadway data in two stages of analysis. First, a screening procedure is used to identify specific locations on the highway network that have hot spot potential. This is followed by a verification procedure, which provides a more detailed analysis of specific locations (e.g., those identified by the screening procedure as having hot spot potential). Both the screening and verification procedures utilize a series of nomographs along with the various traffic and street data to assess hot spot potential. The two procedures are performed manually and are based on EPA's Guidelines for Evaluating Indirect Sources.

PREFACE

This document is the first in a series comprising the Carbon Monoxide Hot Spot Guidelines. The purpose of this series is to provide state and local agencies with a relatively simple yet accurate procedure for assessing carbon monoxide hot spot potential on urban street networks. Included in the Hot Spot Guideline series are:

Volume I: Techniques
Volume II: Rationale
Volume III: Summary Workbook
Volume IV: Documentation of Computer Programs to Generate Volume I Curves and Tables
Volume V: Intersection-Midblock Model User's Manual
Volume VI: Modified ISMAP User's Manual
Volume VII: Example Applications at Waltham/Providence/Washington, D.C.

Hot spots are defined as locations where ambient carbon monoxide concentrations exceed the national ambient air quality standards (NAAQS). For both the 1-hour and 8-hour averaging times the assumption is made throughout these guidelines that a CO hot spot is primarily affected by local vehicle emissions, rather than areawide emissions. Studies have shown that for the 1-hour CO concentration, local sources are the dominant factor. Accordingly, representative urban worst-case meteorological, traffic, and background concentration conditions are selected as those corresponding to the period of maximum local emissions — usually the period of peak traffic. For 8-hour concentrations evidence indicates that neither the local nor the areawide contributions can be assumed to be dominant in every case. However, for the purpose of analysis discussed in these guidelines, local source domination of CO hot spots is assumed for 8-hour averages. This allows some consistency between assumptions in relating the 1-hour and 8-hour CO estimates.

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SECTION I

INTRODUCTION

A. PURPOSE

This volume presents a set of guidelines for the identification and analysis of carbon monoxide "hot spots," which are defined as locations where ambient carbon monoxide concentrations may exceed the national ambient air quality standards (NAAQS). The guidelines are intended for engineers, planners, and others who must consider the air quality effects of traffic management decisions and who are responsible for traffic planning to control CO hot spots. The guidelines present a screening procedure to identify potential carbon monoxide hot spots using only data on automobile traffic volumes, thus obviating time-consuming and costly monitoring of air quality at potential hot spots.

The guidelines also present a hot spot verification procedure that uses more detailed traffic and roadway data to estimate maximum carbon monoxide concentrations at specific locations. The following text discusses in detail the concepts of hot spot screening and verification, and presents the analytical techniques and procedures, as well.

B. OVERVIEW OF THE PROCESS FOR CONTROL OF HOT SPOTS

1. General

Controlling CO hot spots requires (1) the screening of the entire highway network to identify specific locations that are potential hot spots, (2) the detailed analysis of each potential hot spot, and (3) the evaluation, selection, and implementation of control measures. Although these guidelines are primarily concerned with identification and analysis of carbon monoxide problem areas, their ultimate purpose is to allow the selection of suitable control measures to insure the NAAQS for CO.

Choosing among alternative traffic measures for CO hot spot control is much like other public investment decisions. One must balance the benefits and costs an choose accordingly. When the goal is to meet air quality standards, the nature of the choice is somewhat altered because attainment is necessary to protect public health. Consequently, meeting air quality standards should be the first consideration when selecting among alternative actions for control of hot spots. Once that criterion has been satisfied, then the choice among alternatives can be made on the basis of costs and other issues, as with other public investments.

2. Recommended Process

Figure 1 is a flow diagram depicting the overall process for selecting CO control measures. Each of the numbered steps will be briefly described.

a. Step 1: Screening - Screening of roadways and intersections to identify potential CO hot spots is the first task. Screening procedures, presented in Section III of this volume, use generalized procedures and a minimum amount of traffic data; available data can be used in most cases. To facilitate the rapid screening of many locations, simple charts and nomographs are provided. The output is the identification of potential hot spots; no quantitative estimates of CO concentrations are produced.

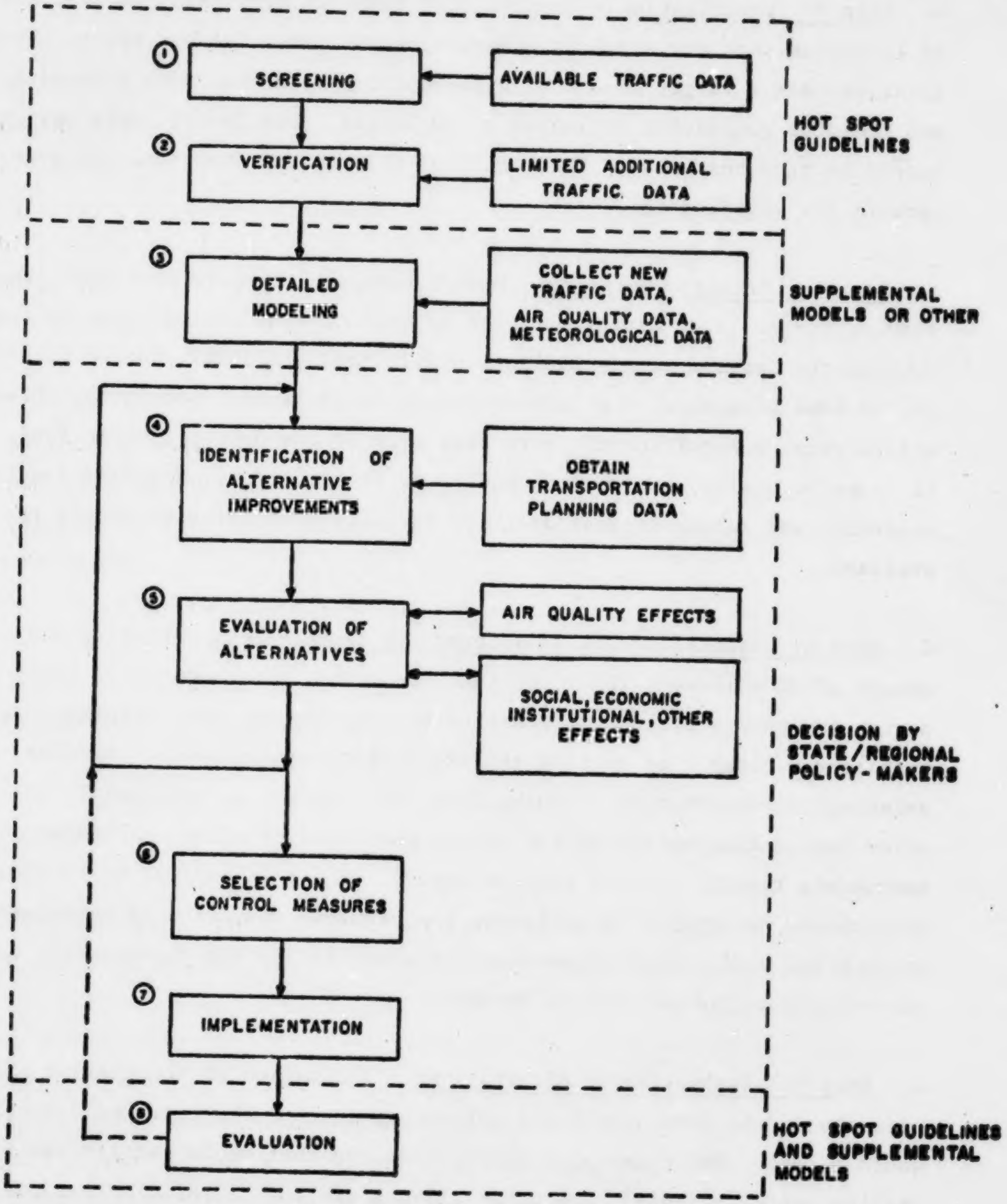
①
SCREENING
AVAILABLE TRAFFIC DATA
②
VERIFICATION
LIMITED ADDITIONAL TRAFFIC DATA
HOT SPOT GUIDELINES
③
DETAILED MODELING
COLLECT NEW TRAFFIC DATA, AIR QUALITY DATA, METEOROLOGICAL DATA
SUPPLEMENTAL MODELS OR OTHER
④
IDENTIFICATION OF ALTERNATIVE IMPROVEMENTS
OBTAIN TRANSPORTATION PLANNING DATA
⑤
EVALUATION OF ALTERNATIVES
AIR QUALITY EFFECTS
SOCIAL, ECONOMIC INSTITUTIONAL, OTHER EFFECTS
DECISION BY STATE/REGIONAL POLICY-MAKERS
⑥
SELECTION OF CONTROL MEASURES
⑦
IMPLEMENTATION
⑧
EVALUATION
HOT SPOT GUIDELINES AND SUPPLEMENTAL MODELS

Figure 1. Decisionmaking process for selecting CO control measures

b. Step 2: Verification - Verification involves more detailed analysis of locations that are shown by screening to be potential hot spots. Verification uses a larger amount of site-specific data than does screening, and produces quantative estimates of CO levels. New traffic data may be needed in many instances. Section IV of this volume describes the procedures for verification.

c. Step 3: Detailed Modeling - Once potential hot spots have been identified, a higher level of analysis can be conducted utilizing computer models such as the Intersection - Midblock Model, Modified ISMAP, CALINE 2, etc., or, in some instances, the Indirect Source Guidelines. Generally, these models require significantly more data than do the Hot Spot Guidelines. In order to utilize the various models to their fullest, detailed traffic, emission, and meteorological data for the site being studied should be available.

d. Step 4: Identification of Alternative Improvements - Knowing the amount of CO emissions reduction that is needed, the planner can begin to narrow the choice of control measures by identifying those alternatives that appear capable of meeting the air quality requirements. New (or existing) transportation planning data are obtained at this point, to allow forecasting emissions for future years and to allow consideration of macroscale traffic changes when necessary. The alternatives to be evaluated should be capable of achieving the required reduction in emissions at each hot spot, after accounting for other mitigating factors such as new vehicle pollution control devices.

e. Step 5: Evaluation of Alternatives - Evaluation of air quality effects uses the models from Step 3 and determines whether the required reductions would be met. For those alternative measures that would satisfy the air quality criteria (only), the other effects are then identified and quantified. If the alternative control measures are inadequate, or if it is prudent to examine additional alternatives because of implementation obstacles that may arise, the process would revert to Step 4 at this point.

f. Step 6: Selection of Control Measures - Selecting among the alternative measures requires balancing the nonair quality effects (assuming that only those measures that will achieve the required reductions are being considered at this point). The thrust of the choice is to minimize the adverse impacts. Often, however, the choice will require weighing effects of various types. For example, the decision might be between two control measures that are similar except that one requires more capital outlay but is more beneficial to fuel consumption. Such choices are commonly made in transporation facility planning. These guidelines cannot detail how to make such choices; an excellent summary of the process has been published[1] and includes a recommended procedure for considering nonmonetary cost and benefits.

g. Step 7: Implementation - Having selected a measure, it must be implemented. When planning for implementation of specific measures, the time to accomplish this step should be considered in all analyses of effectiveness.

h. Step 8: Evaluation - After implementation, the traffic and air quality should be monitored and calculations made to determine if the required reductions in concentrations are being achieved. Rarely are planning predictions exact; in some cases it will be necessary to adjust or supplement the control measures either to meet air quality goals or to ameliorate unexpected impacts.

C. FORMAT OF THE GUIDELINES

It is envisioned that the guidelines will be used by a wide range of individuals, some of whom may not be familiar with various traffic engineering and meteorological concepts. This being the case, it is appropriate that an overview of the technical aspects of traffic on streets and highways, emissions from motor vehicles, meteorological effects, and the interrelationships that exist among these, be provided; this overview is presented in Section II. The actual discussion of the analytical techniques begins in Section III where the screening techniques are presented. Section IV continues the presentation of the Guidelines procedures with a discussion of the verification process. A more detailed discussion of several technical issues mentioned in Sections II, III, and IV is provided in Section V. This Section also provides guidance for the user in selecting several variables that are used at various points in the guidelines procedures. Two specific applications of the guidelines are discussed in Section VI. Specifically, this section considers applying the guidelines first as a method for evaluating the placement of an air quality monitor with regard to the likelihood of it measuring peak carbon monoxide concentrations, and second in the context of carbon monoxide control plan development. The final section, Section VII, presents discussion of the results of a validation study conducted to evaluate the consistency and reasonableness of the guidelines.

Several related documents have been prepared, as well. Volume II[2] of the hot spot guidelines provides a detailed discussion of the rationale behind the guidelines discussed in this document. Volume III[3] provides a summary of the basic elements from this volume that are required to perform hot spot analyses. Its purpose is to serve as a workbook for those involved in applying these techniques in urban hot spot analyses. Volume IV in this series describes a procedure that can be used to update the Guidelines to account for revisions in mobile source emission factors that may occur in the future. Volume IV, then, is not designed for use by the user of the basic Guidelines. Volumes V[5] and VI[6] are user's manuals for computer models that expand the scope of the Guidelines significantly. These models - the Intersection-Midblock Model and the Modified ISMAP Model - enable the analyst to perform very detailed studies of carbon monoxide levels using specific meteorological and emission source parameters. Finally, Volume VII describes the application of the Guidelines in the analysis of hot spot potential in Waltham, Massachusetts and Washington, D.C., and reports a demonstration of using the Guidelines as a tool for evaluating the impact of a revised traffic circulation plan in Providence, Rhode Island, on local carbon monoxide concentrations.

SECTION II

OVERVIEW OF MOBILE SOURCE CARBON MONOXIDE EMISSIONS AND AIR QUALITY

A. INTRODUCTION

This section provides an overview of a number of fundamental issues concerning carbon monoxide, it sources, and its impact on air quality. The purpose of this section is to provide those users who do not have at least basic familiarity with various concepts of emission characteristics, traffic engineering, or meteorology, with an indication of the interrelationships that exist among these parameters and how these ultimately affect air quality. Individuals who have a working knowledge of various air quality concepts may choose to skip this section.

B. BACKGROUND

Carbon monoxide is a colorless, odorless, tasteless, relatively inert gas that is formed principally as a by-product of incomplete combustion. The dominant source of carbon monoxide emissions is the internal combustion engine. In fact, it has been estimated that some 76 percent of the total carbon monoxide emissions that occurred in the United States during 1972 were directly attributable to transportation sources associated with the internal combustion engine.

Because deleterious effects are associated with exposure of humans to carbon monoxide, efforts are being made to reduce, where necessary, high ambient carbon monoxide concentrations. In this regard, the federal Clean Air Act of 1970 was enacted as a mechanism for establishing specific limits for ambient concentrations of carbon monoxide, and for providing the legal mandates to ensure that efforts would be expended by state and local governments to meet these limits. These limits, the NAAQS, are that 1-hour average ambient concentration of CO must not exceed 40 mg/m^3 (35 ppm) more than once a year, and that 8-hour average concentrations must not exceed 10 mg/m^3 (9 ppm) more than once per year during nonoverlapping periods.* Experience has shown that the 8-hour standard is the more often violated.

Because carbon monoxide is a primary product of combustion, relatively inert, and released near the ground, the highest ambient concentrations are typically found in the immediate vicinity of the emission source. Hence, studies of carbon monoxide problems must focus on local analyses rather than areawide analyses of the type undertaken for other pollutants like oxidants and SO_2. The highest concentrations are also most likely to be found at locations with the highest emission rates. In this regard, the locations of most interest for hot spot analysis are near points of heavy traffic flow or traffic congestion.

C. CONCENTRATION, EMISSIONS, and EMISSION SOURCES

1. Concentrations

Analyses of CO hot spots focus primarily on determining the magnitude of ambient concentrations that can be expected to occur at a specified location, and relating this concentration to a corresponding standard. In this connection, then, it is necessary to understand the factors that directly affect concentrations in the general vicinity of an emissions source.

---

*Nonoverlapping in this case implies that there are no common 1-hour time increments included in two or more 8-hour averaging periods. Thus, for a period of, say, 16 hours, there are a total of nine continuous 8-hour periods; however, only two of these periods- the first hour through the eighth hour, and the ninth hour through the sixteenth hour- are nonoverlapping.

A very basic concept is that a concentration is a relative quantity; in hot spot analyses, it is the quantity of carbon monoxide relative to a quantity of ambient air. This is usually expressed in mass per volume or in parts (of carbon monoxide) per million (parts of ambient air). The concentration of carbon monoxide occurring at any point is primarily a function of three determinants including (1) the rate that the carbon monoxide is discharged into the ambient air by various sources; (2) the forces that act to disperse, dilute, or transport the carbon monoxide once it is emitted into the ambient air; and (3) the orientation of the point of interest with respect to the primary emission source(s).

Carbon monoxide concentrations occurring in the immediate vicinity of a street or highway are generally considered to be comprised of two components, including (1) a concentration directly attributable to the nearby roadway, and (3) a background component that is attributable to all other emission sources. This can be represented by the equation:

$$\chi_T = \chi_R + \chi_B \tag{1}$$

where χ_T = the total concentration of carbon monoxide occurring at a given location

χ_R = the component attributable to nearby sources

χ_B = the background component.

The first component, χ_R, is a function of several variables and can be expressed by the equation:

$$\chi_R = V \cdot E \cdot K \cdot 1/u \tag{2}$$

where V = traffic volume (in vehicles per day);

E = average emission rate (in grams per vehicle-mile) for all vehicles comprising V;

K = Proportionality factor that accounts for factors such as the orientation of the point of interest with respect to the source, and other factors that determine the dispersion characteristics; and

u = wind speed.

It can be seen from Equation 2 that at a given location, χ_R is directly proportional to both traffic volume and emission rate, and inversely proportional to wind speed. The determinants of χ_R will be discussed in detail in a subsequent portion of this section.

The second component of χ_T is the background concentration, χ_B. *Background concentration* can be defined as an ambient concentration occurring as a result of the areawide (extraurban plus intraurban) diffusion of carbon monoxide from all sources. Background concentrations are generally considered to be more or less uniform throughout large areas of similar development intensity (i.e., areas such as metropolitan core area, suburban areas, rural areas, etc.). Analyses of air quality modeling data reflecting 1974 conditions for large metropolitan areas such as Boston and Springfield, Massachusetts, indicate background concentrations in the range of 2.9 to 5.9 mg/m^3 averaged over a 1-hour period. Normalizing this to 1982 conditions results in a range of 1.7 to 2.9 mg/m^3.

In most instances where carbon monoxide concentrations are high enough to warrant concern, it has been found that the roadway component, χ_R, is generally substantially more important than the background component. Consequently, the procedures presented in this document focus primarily on estimating the roadway component, χ_R, and then adding a measured or assumed background component to the computed roadway component to derive an estimate of the total concentration. A methodology for estimating area-specific background concentration is provided, however, in Section V.B, and this may be used when the requisite data are available.

2. Emissions and Emission Sources

It was indicated that the primary concern here is with emissions of carbon monoxide from highway traffic. The amount of carbon monoxide emitted from traffic is directly proportional to the number of vehicles in the traffic stream. There are, however, a number of other factors that also affect the amount of any contaminant produced for a given volume of traffic, and these factors are discussed in the following paragraphs.

a. Dimensioning Emissions - In order to provide a quantitative parameter with which to analyze carbon monoxide problems, emissions from any source are generally described in terms of an emissions rate. Two *emission rates* are of importance in hot spot analyses—these describe the amount of carbon monoxide (in grams) emitted either for given units of distance and time (meters, seconds), or for a specific unit of time (usually 1 second). Ordinarily, the emission rate of a moving vehicle is described in either grams per mile or grams per kilometer while for an idling vehicle, grams per minute is commonly used.

b. Emission Rates - The actual emission rate for any vehicle varies widely according to two primary factors including (1) the operational characteristics of the vehicle such as travel speed, acceleration rate, etc., and (2) environmental conditions such as ambient temperature or altitude. In order to provide a tractable method for estimating the quantity of emissions produced from vehicular traffic, the entire vehicle population is distributed among six general categories, each of which displays unique emission characteristics, and use is made of composite emission rate for all vehicles in each category. This rate is based on a typical driving cycle and accounts for emission variability due to operational and environmental conditions. The individual categories include:

- light-duty, gasoline-powered vehicles - LDV (passenger cars)
- light-duty, gasoline-powered trucks - LDT (trucks up to 8,500 pounds gross vehicle weight)

- heavy-duty, gasoline-powered vehicles - HDV-G (vehicles over 8,500 pounds gross vehicle weight)
- light-duty, diesel-powered vehicles - LDV-D
- heavy-duty, diesel-powered vehicles - HDV-D
- motorcycles - MC

The four categories involving gasoline-powered vehicles are each subdivided further. This subcategorization is based on (1) engine design (four-cycle or two-cycle operation) for motorcycles only, and (2) model year for the other three categories. Model year distribution is important because emission control devices differ in design and effectiveness by model year. Also, most emission control devices tend to become less effective with time in use, therefore vehicle emission rates will generally increase with accumulated mileage (mileage correlates very well statistically with vehicle age). Diesel-powered vehicles generally display a rather uniform carbon monoxide emission rate that tends to be substantially lower than a gasoline engine of corresponding size and rating; hence, additional carbon monoxide emission control devices have not been required on these types of vehicles. Owing to these factors, there is no real need to consider emission rates separately by model year for diesel-powered vehicles.

Large-scale testing by the U.S. Environmental Protection Agency of vehicles in each category (and model-year subcategory) has resulted in the definition of composite emission rate for each vehicle category. The composite emission rate implicitly reflects a specific set of prevailing operational and environmental conditions. The emission rates that are most widely used in the analysis of carbon monoxide emissions generated by motor vehicles are those developed by the U.S. Environmental Protection Agency and reported in Automobile Exhaust Emission Modal Analysis Model[7] and MOBILE I.[8] These documents describe both the implicit operating and environmental conditions, and methods for adjusting the emission rates to reflect other operational and environmental characteristics. The reader should refer to these two reports for details.

c. Emission Factors - An *emission factor* is the average emission rate (gm/km) for all vehicles within a specific subcategory (vehicle type by model year, or engine type for motorcycles) that reflects specific operating and environmental conditions.

A *composite emission factor* is the average emission rate for all vehicles within one of the six vehicle-type categories, or all categories combined, that reflects specific operating and environmental conditions, and has been weighted according to a particular distribution of model-year vehicles within the category or categories.

d. Emission Quantities - The quantity of carbon monoxide emitted by an individual vehcle is a function of the emission rate (expressed as an emission factor) and an operating time or distance parameter (minutes, seconds, miles, or kilometers). In considering a finite section of roadway, then, the quantity of carbon monoxide produced during a given time period (say, 24-hours) can be expressed as:

$$Q = d\Big[\Big(C'_{LDV}\Big)\Big(n_{LDV}\Big) + \Big(C'_{LDT}\ \ \Big(n_{LDT}\Big) + \Big(C'_{HDV-G}\Big)\Big(n_{HDV-G}\Big) + \Big(C'_{HDV-D}\Big)\Big(n_{HDV-D}\Big) + \Big(C'_{LDV-D}\Big)\Big(n_{LDV-D}\Big) + \Big(C'_{MC}\Big)\Big(n_{MC}\Big)\Big] \qquad (3)$$

where Q = the total emissions produced, grams;

d = the length of the section, kilometers;

C'_{LDV} = composite emission factor for light-duty vehicles, gm/km;

C'_{LDT} = composite emission factor for light-duty trucks, gm/km;

C'_{HDV-G} = composite emission factor for heavy-duty, gasoline-powered trucks, gm/km;

C'_{HDV-D} = composite emission factor for heavy-duty, diesel-powered trucks, gm/km;

C'_{LDV-D} = composite emission factor for light-duty, diesel-powered vehicles, gm/km;

C'_{MC} = composite emission factor for motorcycles, gm/km;

n_{LDV} = the number of light-duty vehicles traversing the section during 24 hours;

n_{LDT} = the number of light-duty trucks traversing the section during 24 hours;

n_{HDV-G} = the number of heavy-duty trucks traversing the section during 24 hours;

n_{HDV-D} = the number of heavy-duty, diesel-powered trucks traversing the section during 24 hours;

n_{LDV-D} = the number of light-duty, diesel-powered vehicles traversing the section during 24 hours; and

n_{MC} = the number of motorcycles traversing the section during 24 hours;

Two emission quantities are important in considering carbon monoxide concentrations on highway systems. The first - *free flow emissions* - is defined as the quantity of emissions produced during a specified time-period by vehicles that are (assumed to be) traveling at a relatively constant, though not necessarily uniform, rate without interruptions. The second quantity - *excess emissions* - is defined as the quantity of emissions above the cruise emissions component produced during a specified time-period by vehicles during acceleration, deceleration, and idling modes. It should be apparent then, that free flow emissions are of the greatest interest when considering carbon monoxide emissions resulting from highways or street sections where traffic flows fairly smoothly without interruption. On the other hand, where interruptions are expected and do occur (for instance at intersections) both free flow and excess emissions are important. It should be noted that the largest portion of the total emission generated at signalized intersections is often associated with the excess emissions from accelerating, decelerating, and idling vehicles.

The CO emission factors assumed in deriving Figures 7 through 28 in the next section were obtained by using the emission factor information for a national average mix of vehicles (by model year) derived from MOBILE I[8] for the calendar year 1982 and speed correction factors from the same reference. It was assumed that 20 percent of these vehicles are operating from a cold start and approximately 88 percent of the vehicle mileage is attributable to light-duty vehicles, 8 percent is the result of light-duty trucks, and 4 percent from heavy-duty vehicles.

The emission factors used in deriving Figures 7 through 28 were estimated using the Automobile Exhaust Emission Modal Analysis Model.[7] Combinations of vehicle operating modes used in the model were similar to observed traffic in the vicinity of a signalized intersection. Since the Automobile Exhaust Emission Modal Analysis Model assumes that there are no vehicles operating from a cold start, a correction factor was applied to the estimates obtained with the model to reflect an assumption of 20 percent cold starts. This was done so that all the curves in Section III reflect consistent assumptions about the percentage of cold starts. The ambient temperature was assumed to be 0°C.

3. Emission Source Considerations

It was indicated previously that the rate at which carbon monoxide is generated from a motor vehicle is primarily a function of the operating characteristics of the vehicle and the prevailing environmental conditions. These two parameters, which are fundamental in any analysis of highway-generated emissions, are discussed in detail here.

a. Operational and Environmental Aspects of Traffic - In this context, operational aspects include the mode of operation - accelerating, decelerating, idling, or cruising, and the rates thereof. Environmental aspects include two categories; traffic environment and atmospheric environment; the interest at this point is with the traffic environment.

Design speed is a speed selected for purposes of design and correlation of those features of a highway, such as curvature, superelevation, and sight distance, upon which the safe operation of vehicles is dependent. *Average highway speed* is the weighted average of the design speeds within a highway section, when each subsection within the section is considered to have an individual design speed. *Cruise speed* or *operating speed* is the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.

The interrelationship among traffic operating parameters, traffic environment, and emissions produced is quite complex. In this relationship the quantity of emissions produced is directly related to traffic operating parameters such as cruise speed or idling time. In turn, the traffic environment to a large degree determines the operating characteristics for any given roadway. Several of the most important elements of the traffic environment include the physical features of the roadway, the density and composition of traffic, and the geographic location of the facility.

Perhaps the most important manifestation of the various elements of the traffic environment is that collectively they determine the roadway's capacity, which (as will be demonstrated later) is one of the two parameters that directly affects roadway operating characteristics. Roadway capacity is a fundamental topic in the traffic engineering field, and it has been the subject of much research over the past years. Perhaps the most comprehensive documentation of the topic is the Highway Research Board's 1965 Highway Capacity Manual.[9]

Highway capacity can be defined as the rate of traffic flow (usually in vehicles per hour) that can be accommodated under certain defined conditions. Note that the definition of capacity involves both a rate of traffic flow and a specific set of conditions. These specific conditions, referred to as prevailing conditions, include two general categories - prevailing roadway conditions, and prevailing traffic conditions. *Prevailing roadway* conditions are those established by the physical features of the roadway and are therefore relatively fixed or constant with respect to short time intervals; these include items such as the number of lanes available, topographic characteristics, and the presence of flow constraints such as narrow bridges or traffic signals. *Prevailing traffic conditions* are those that depend on the nature of traffic using the roadway, and therefore, can and do change from hour-to-hour; examples include the relative number of cars, trucks, and buses in the vehicle stream, and the density of traffic on the facility. Prevailing conditions can be described also in terms of level of service. *Level of service* is a term used to indicate the qualitative aspects of traffic flow. Considered in level of service are a number of factors including speed, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating cost. In practice, six levels of service are used to describe the qualitative aspects of traffic on street sections that are not influenced by intersections; these various levels of service are described in the Highway Capacity Manual[9] as follows:

> *Level of service A* describes a condition of free flow, with low volumes and high speeds. Traffic density is low, with speeds controlled by driver desires, speed limits, and physical roadway conditions. There is little or no restriction in maneuverability due to the presence of other vehicles, and drivers can maintain their desired speeds with little or no delay.
>
> *Level of service B* is in the zone of stable flow, with operating speeds beginning to be restricted somewhat by traffic conditions. Drivers still have reasonable freedom to select their speed and lane of operation. Reductions in speed are not unreasonable, with a low probability of traffic flow being restricted. The lower limit (lowest speed, highest volume) of this level of service has been associated with service volumes used in the design of rural highways.
>
> *Level of service C* is still in the zone of stable flow, but speeds and maneuverability are more closely controlled by the higher volumes. Most of the drivers are restricted in their freedom to select their own speed, change lanes, or pass. A relatively satisfactory operating speed is still obtained, with service volumes perhaps suitable for urban design practice.

> *Level of service D* approaches unstable flow, with tolerable operating speeds being maintained though considerably affected by changes in operating conditions. Fluctuations in volume and temporary restrictions to flow may cause substantial drops in operating speeds. Drivers have little freedom to maneuver, and comfort and convenience are low, but conditions can be tolerated for short periods of time.
>
> *Level of service E* cannot be described by speed alone, but represents operations at even lower operating speeds than in level D, with volumes at or near the capacity of the highway. At capacity, speeds are typically, but not always, in the neighborhood of 30 mph. Flow is unstable, and there may be stoppages of momentary duration.
>
> *Level of service F* describes forced flow operation at low speeds, where volumes are below capacity. These conditions usually result from queues of vehicles backing up from a restriction downstream. The section under study will be serving as a storage area during parts or all of the peak hour. Speeds are reduced substantially and stoppages may occur for short or long periods of time because of the downstream congestion. In the extreme, both speed and volume can drop to zero.

Capacity of a roadway section then, is specified as the capacity at a particular level of service. The term capacity by itself, however, is understood to imply level of service E; this is the level of service at which the maximum capacity occurs. When referring to capacity at a level of service other than E, the term service volume is used (qualified by adding the appropriate level of service).

Research as to the nature of highway operating characteristics has provided the means for estimating the capacity (service volume at level of service E) of both intersections and highway segments away from the influence of intersections. An important result of this research has been to define a relationship among various operating parameters including volume, capacity, operating speed, and level of service. A general schematic representation of this relationship is shown in Figure 2. This figure shows that the speed and level of service deteriorate as the volume (expressed as a ratio with the capacity of the facility) increases. Also, it is shown that once conditions of forced flow and congestion (corresponding to level of service F) occur, both speed and volume decrease dramatically. While Figure 2 is intended only to illustrate a concept, the actual numerical

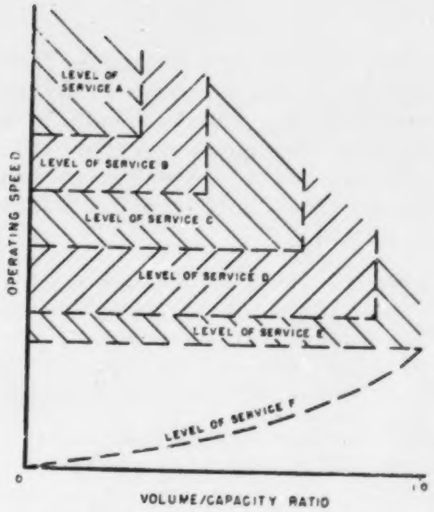

Figure 2. General concept of relationship of levels of service to operating speed and volume capacity ratio (not to scale)

relationship can be developed for any specific highway-type. In this derived relationship, level of service and speed characteristics can be developed as a function of volume and capacity. The actual relationships will not be discussed here; rather, the reader if referred to the Highway Capacity Manual[9] or other traffic engineering texts.

The discussion above focuses primarily on segments of streets and highways that are not influenced by intersections or other disruptions to normal flow. It should be noted that the same types of relationships can be established for intersections; however, in these relationships the primary consideration is not with operating speed but with parameters that relate to the amount of delay expected at the intersection. It should be obvious that traffic operating characteristics are predictable to the extent that information regarding the volume and capacity of the highway is available. This concept is important because it provides the basis for an important assumption used in developing the relatively simple technique presented in this document for evaluating possible carbon monoxide problems. Since the volume and capacity parameters are such key elements of the evaluation procedure, further discussion of these are warranted.

As stated, capacity (service volume at level of service E) refers to the probable maximum number of vehicles that could pass a point on a roadway during a given unit of time (usually vehicles per hour). The factors that influence capacity vary with the type and location of the facility being considered. Three general categories of capacity analysis can be discussed; these include (1) analvsis of freeways and expressways, (2) analysis of urban streets and arterials, and (3) analysis of rural highways and arterials.

Freeways and expressways can generally be considered multilane facilities (at least two lanes in each direction) characterized by the fact that direct access to abutting land-use is eliminated in favor of exclusive service to moving traffic. These facilities can also be considered to be comprised of several components, each with separate capacity characteristics. The separate components include: (1) the basic freeway section, (2) weaving sections, and (3) ramp junctions. The capacity of a basic section is about 2,000 passenger cars per hour per lane under "ideal" conditions. In its standard usage ideal conditions imply:

- no commercial vehicles in the traffic stream
- the design of the roadway is suitable for operating speeds of 70 miles per hour*
- lanes are 12 feet wide
- no lateral obstructions within 6 feet of the pavement edge

When prevailing conditions are less than ideal, capacity is reduced. Therefore, it is apparent that capacity is a function of elements such as:

- the percentage of trucks and buses in the traffic stream
- design characteristics such as the horizontal and vertical alignment
- lane widths
- laterial clearance

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*This does not imply that the actual operating speed is 70 miles per hour.

For weaving sections and ramp junctions, capacity is a function of the same factors plus several additional elements that take into account the friction developed in the free flowing traffic stream by the merging and weaving activity. In order to account for the impact of these capacity constraints, correction factors have been developed. These factors, as well as the technique for applying them, are presented and discussed in detail in the Highway Capacity Manual.[9]

The second general category pertains to capacity on urban streets and arterials. Unlike freeways and expressways, urban streets and arterials are intended to provide access to adjacent land development. The resulting potential for interference from vehicles entering or leaving the traffic stream significantly affects the capacity of a street. Of particular importance in analyzing capacity on urban streets and arterials is the consideration of intersections, especially signalized intersections.

Signalized intersections generally place the greatest constraint on the capacity of urban arterials. This is so because it can be expected that during a given time period, some fraction of the vehicles using the roadway will be required to stop for a red signal. Obviously then, an important determinant of the capacity of any intersection approach is the amount of "green" signal time available for each approach. In traffic engineering practice, the allocation of green time to an approach is expressed in terms of the ratio of the green time (in seconds) allocated per cycle, to the total cycle length (in seconds); this ratio is designated *G/Cy*.*

The G/Cy value assigned to an intersection approach is a function of the volume demand on that approach and the demand on the approach plus the demand on other approaches. More specifically, the G/Cy for an approach is a function of the critical approach volumes during each separate signal phase. Several definitions concerning traffic signals are required at this point. First, *critical approach volume* is defined as the highest hourly lane volume for all approaches that are allocated concurrent green time. Obviously then, there are at least two critical approach volumes associated with a signalized intersection.

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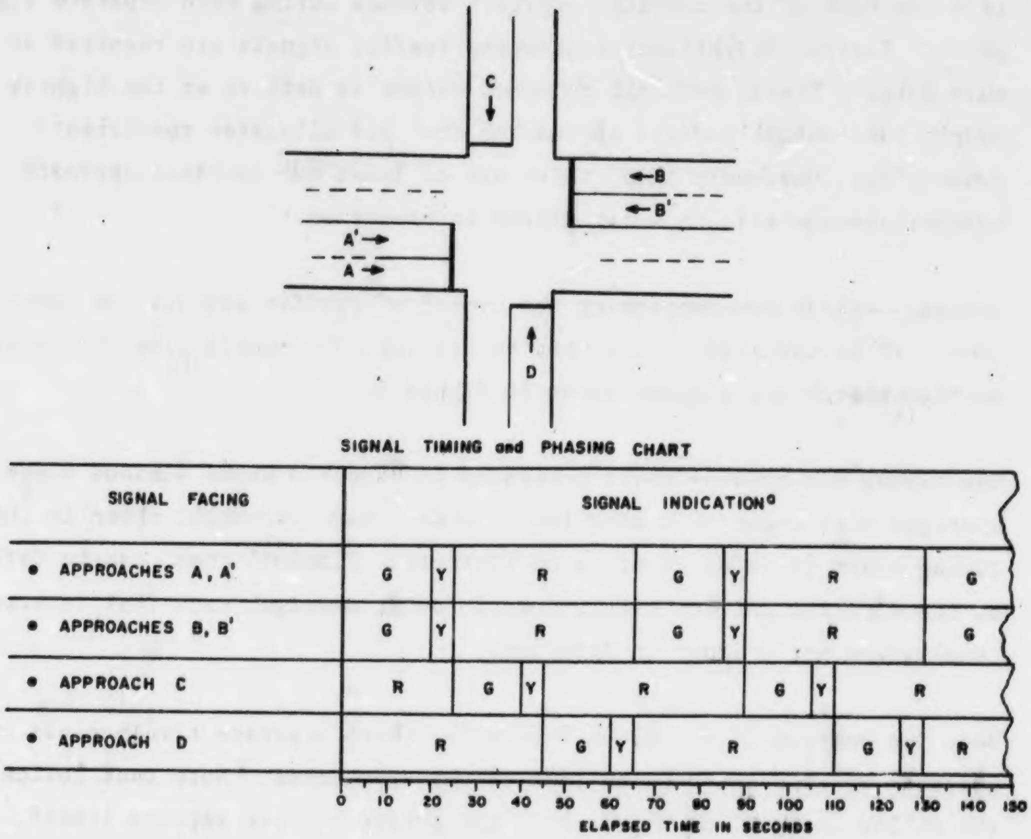
*Normally the designation is G/C; G/Cy will be used in this report, however, for the sake of consistency since this designation has been used in previous, related reports.

Several definitions concerning the timing of traffic signals are important, also. These definitions can best be developed by considering the intersection sketch and diagram shown in Figure 3.

The timing and phasing chart presented in Figure 3 shows various signal messages that occur as a function of time. Each increment shown in the timing chart is referred to as an interval. *Interval* then, can be defined as the duration for any signal indication or message; note that intervals usually are not uniform in duration.

Note the pattern of the green intervals; three separate time periods are utilized in allocating green time to the approaches. Note that following the yellow interval on approach D, the entire pattern repeats itself. The time period beginning at "time 0," to the point where the pattern begins to repeat (i.e., at the end of the yellow interval for approach D) is referred to as a cycle. By definition, a *cycle* is the time required for a complete set of interval sequences to occur. *Optimum cycle length* is the theoretical cycle length that will minimize total delay time at the intersection. Notice too, the pattern of green intervals occurring during the cycle; three separate, nonoverlapping time periods are utilized in allocating green time to the approaches. This indicates that the signal represented in Figure 3 uses three phases. A *phase* is defined as a portion of the cycle where a major movement is permitted.


C
B
B'
A'
A
D
SIGNAL TIMING and PHASING CHART
SIGNAL FACING
SIGNAL INDICATION^a
• APPROACHES A, A'
G Y R G Y R G
• APPROACHES B, B'
G Y R G Y R G
• APPROACH C
R G Y R G Y R
• APPROACH D
R G Y R G Y R
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
ELAPSED TIME IN SECONDS

^a CODES: G=GREEN, Y=YELLOW, R=RED

Figure 3. Signal timing and phasing at intersections

Traffic signals are operated by a controller unit, which can be one of several general types. *Fixed-time controllers* are internally programmed devices that provide for as many as three separate timing and phasing combinations for an installation. For certain applications these are being replaced by more flexible and efficient *actuated controllers* that allocate green time, phasing, and timing according to the traffic demand on each approach.

The last consideration is whether or not a signal is part of a coordinated system of signals. *Interconnected signals* are signal systems that provide coordinated control over two or more separate intersections; this type of system is designed to coordinate the movement of platoons of vehicles so that a platoon arrives at a signal at the beginning of the green interval. This effectively reduces the total delay time at each intersection. *Isolated signals* are those that operate independently of other nearby signals. A summary of the most important considerations for signalized intersections appears in Table 1.

Table 1. IMPORTANT FEATURES OF TRAFFIC SIGNAL INSTALLATIONS WITH REGARD TO THE IMPACT ON TRAFFIC OPERATION

Parameter	Units	Remarks
• Cycle length	Seconds	Generally in the range of 40 to 120 seconds. Constant for fixed-time installations, variable (within certain limits) for actuated systems. Longer cycles minimize queue length but increase total delay time for stopped vehicles.
• Optimum cycle length	Seconds	Primarily a theoretical value.
• Number of phases (per cycle)	None	Generally 2 to 4 phases can be used — more are possible. Fewest phases possible are used. Number of phases may vary for actuated systems or fixed-time systems with on-call pedestrian signals.
• Interval	Seconds	Varies considerably for different indications. Yellow interval generally 4 to 6 seconds; green usually a minimum of 10 seconds.
• Critical volume	Vehicles per hour	Directly related to green time allocated. Critical volume is defined for each phase.

Several texts contain detailed explanations of traffic signal operations and theory; included are the Highway Capacity Manual,[9] and the Institute of Transportation Engineer's Transportation and Traffic Engineering Handbook.[10]

Capacity of intersection approaches controlled by STOP signs has not received wide attention. Several studies have shown large variations in capacity for different intersection configurations. A method for estimating the capacity of STOP-sign controlled approaches is presented in Section IV.

Several additional, more subtle factors also affect capacity and operation; these include (1) the size of the metropolitan area, (2) the distribution of the volume demand during a given time-period (usually an hour), (3) the number and width of approach lanes, and (4) the amount of interference to flow caused by turning vehicles, pedestrians, buses (loading or unloading), and the proportion of heavy trucks and buses in the traffic stream. These factors and the manner in which they affect capacity are discussed in detail in the Highway Capacity Manual.[9]

Again, the importance of capacity determination for highway sections not influenced by intersections is that it provides a basis for estimating travel speed, which is the primary determinant of emissions for these types of facilities. At intersections, conditions of both interrupted and uninterrupted flow occur. The free-flowing traffic is assumed to emit carbon monoxide uniformly over a infinite line located at the centerline of each traffic stream (as in the expressway location). Excess emissions resulting from vehicle acceleration, deceleration, and idling are assumed to be emitted over finite segments of each traffic stream. The length of these finite line sources is determined by the average queue length that develops on each intersection approach as a result of the imposed delay. The quantity of emissions generated is a function of delay time, queue length, and acceleration/deceleration rates, as well as cruise speed; each of these factors is related to the capacity of the intersection.

An important expression of the utilization of a roadway is the *volume-to-capacity ratio (v/c)*. The volume to capacity ratios are most often used to express the relationship between (1) peak hour approach volume and approach capacity for a particular approach of an intersection, or (2) the total peak hour volume (in one direction) and free flow capacity for a highway or midblock arterial street section. As was shown in Figure 2, v/c is the primary determinant of operating speed for free flowing roadways. The v/c for signalized intersections is the key parameter for estimating both *queue lengths*, the length of the line formed by vehicles waiting at a red signal message, and *delay time*, the product of the average duration of the stopped time at a signal, and the average number of vehicles required to stop per cycle. This relation is significant because, as was indicated previously, vehicles required to decelerate, idle, and accelerate account for the excess emissions, which usually comprise the largest portion of total emissions generated at an intersection.

The volume element of v/c is obviously an important parameter. Several different terms are used to describe various measures of traffic volume. Perhaps the most widely used measure of traffic volume is the *average daily traffic volume* or *ADT*, which is defined as the average 24-hour volume accommodated by a roadway in both directions for a specified time-period, usually from 1 to 3 months. *Average weekday traffic (AWDT)* is conceptually similar to ADT except that it (AWDT) is computed for weekday (Monday through Friday) traffic volumes only. *Average annual daily traffic (AADT)* is the total yearly volume accomodated divided by the number of days in the year. *Peak-hour volume* is the highest number of vehicles determined to be passing through a roadway section during 60 consecutive minutes. *Peak-hour volume* can also be described in terms of peak-hour lane volume. *Peak-hour lane volume* refers to the individual lane volumes that occur during the peak hour. It should be noted that the peak-hour lane volume may not represent the highest hourly volume for each lane since the peak hour is determined by either the total roadway volume or the total volume entering an intersection. For convenience, the *peak-hour average lane volume* can often be used for many analytical procedures. This volume is simply the total volume for one direction divided by the number of lanes (excluding special purpose lanes such as turning or acceleration lanes) available to accommodate traffic moving in that direction.

An indication of the volume demand distribution during the peak hour is provided by the peak-hour factor. The *peak-hour factor* describes the ratio of the total peak-hour volume to the maximum flow rate during a given time increment during the peak hour; this ratio must be qualified by the specified time increment during which the maximum flow rate was computed. The maximum flow rate (expressed in vehicles per hour) is typically computed for time increments of 5 or 6 minutes for free-flowing traffic, or for 15-minute increments for intersections. The peak-hour factor has a maximum value of 1.0, which would indicate that the demand during the hour does not vary to any significant extent.

Other types of volume data are routinely collected during typical traffic studies. *Vehicle classification counts* are conducted to determine the distribution of various types of vehicles using a facility. The proportions are somewhat uniform between similar types of facilities, but between facilities that perform dissimilar functions, wide variations usually occur. *Lane distribution* is a parameter that defines the proportion of the total roadway volume, usually for 1-hour increments, using each lane. Similarly, *directional distribution* or directional split (again, usually by hourly increments) for a highway is the proportion of the ADT on a given traffic stream. The directional split for the peak hour should be used for a worst case analysis.

Traffic volume patterns are typically uniform from day-to-day. This is true to the extent that relative volumes for specific seasons, months, days, or hours can be predicted from established trend data. This uniformity in volume patterns permits large scale analyses to be accomplished with a relatively low level of effort directed at field counting programs. This is a significant issue here since the procedures presented for analyzing hot spots rely very heavily on areawide traffic volume data. Substantial quantities of areawide volume data are often available from state or local traffic engineering or planning agencies; therefore, the techniques presented herein are considered to provide a realistic approach to analyzing hot spot potential on an areawide basis.

b. Other Environmental Considerations - Two parameters that are not related to either traffic operation or roadway environment have a significant effect on vehicular emissions. The first of these is the ambient temperature.

In order for ignition to occur in a gasoline engine, the fuel must be vaporized just prior to the ignition phase, and also there must be an appropriate balance (ratio) between the quantities of vaporized fuel and air that are present. Gasoline does not vaporize as readily when it is cold as it does when temperatures are high. Therefore, when a "cold" engine is being started, the quantity of gasoline that vaporizes is much less than when the engine is operating at normal temperatures. To compensate for this temporary imbalance in the ratio of vaporized fuel to air, gasoline engines are equipped with a choke, which increases the quantity of fuel taken into the combustion chamber and therefore reduces the effective imbalance in the ratio and expediting fuel ignition.

Although the ratio of air to vaporized fuel becomes balanced when the choke is functioning, the ratio of total air to fuel becomes imbalanced because of the lack of the proper amount of combustion air. This imbalance results in incomplete fuel combustion. A major product of incomplete combustion of gasoline is carbon monoxide. Therefore, it is obvious that temperature has some effect on emission rates.

The total implication of ambient temperature becomes apparent after considering the effects on an engine's operation. The amount of fuel that is vaporized diminishes as temperature decreases. As a result, fuel entering the combustion chamber of an engine during the first minutes of operation tends to quench the cylinder walls, thereby delaying attainment of the stabilized temperature. The extent of this quenching phenomenon is inversely proportional to temperature. Secondly, the choke on most vehicles is actuated by a sensor incorporated into a temperature sensitive engine component such as the exhaust manifold. The rise-time from ambient to stabilized temperature for such components lags the rise-time in the combustion chamber by various amounts of time, thereby assuring adequate choke-on time. The actual rise-time is a function of ambient temperature. Figure 4 provides an indication of choke-on time as a function of temperature based on tests described in Reference 11.

Ambient temperature and time in operation parameters have an additional impact on vehicles equipped with catalytic converters. During the first several minutes of operation, the converter bed is not at the optimum temperature for CO oxidation, therefore the CO emission rate during the first few minutes of operation is greater than at the point when the optimum converter bed temperature is reached. Various analyses have shown that time required for the converter bed to reach the designed operating temperature is a function of ambient temperature.

Once the engine and converter bed temperature have stabilized and the choke has opened, ambient temperature does not have a significant effect on the emission rate. Obviously then, the effect of temperature variations is limited by time. The increment during which temperature effects occur (defined as the first 505 seconds of operation after the engine has not been run for at least 4 hours for noncatalyst vehicles, and 1 hour for catalyst vehicles) is referred to as the *cold-start operating mode*. The amount of time that a vehicle remains at ambient temperature with the engine not operating is defined as the *cold soak period*.

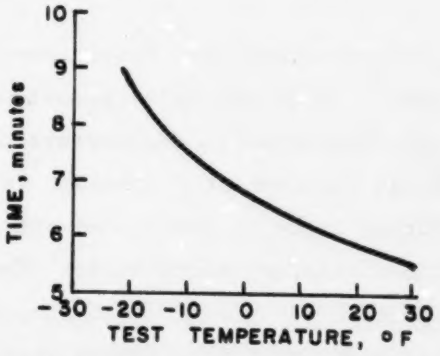


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Figure 4. Representation of choke-on time as a function of temperature

The emission rate is also affected if the vehicle is restarted shortly after being shut off. This is so because the temperature of both the air under the hood and various engine components increases upon engine shutdown since the engine cooling systems (fan and water circulation) cease functioning as well. The higher temperature air is less dense than the normally cooler air, therefore the air to fuel ratio is reduced resulting in higher emissions. Operation during the relatively short duration that emissions are affected as a result of heat build-up is referred to as *hot start operation*. The emission rate during hot-start operation is only slightly greater than the rate during stabilized operation.

The second of the two environmental parameters is the altitude of the location under consideration. Atmospheric pressure decreases with altitude, therefore the mass of any given volume of air also decreases. The result is that a stoichiometric imbalance occurs in the fuel combustion phase of the engine operating cycle because of a deficiency in the mass of available combustion air. Gasoline engines, then, tend to "burn rich" (lower than desirable air-to-fuel ratio) at high altitudes, which has the same net result as actuating the choke - carbon monoxide emissions increase significantly.

D. RELATIONSHIP BETWEEN EMISSIONS AND RESULTING CONCENTRATIONS

The previous discussion served to define various concepts concerning carbon monoxide concentrations, and carbon monoxide emissions, including emission sources, and factors affecting emission rates; the concepts of concentrations and emissions were however, discussed as separate issues. It is of interest to consider the relationship that obviously exists between the carbon monoxide emissions generated along a street or highway, and the resulting concentrations measured at some point nearby.

Along expressways and arterial streets where conditions of uninterrupted flow prevail, carbon monoxide emissions are assumed to be uniform over the entire length of a traffic stream. A *traffic stream* is defined as all traffic lanes in one direction of travel. Furthermore, all emissions are assumed to originate from the centerline of each traffic stream. Given a uniform emission rate (based on traffic speed and volume), the CO concentration at a given location depends upon how much the emission is diluted with ambient air between the emission source (treated as an infinite line) and the receptor site. Four factors influence this dilution, (1) atmospheric turbulence, (2) wind speed, (3) distance between the receptor and emission source, and (4) wind/road angle.

Atmospheric turbulence is induced by buoyancy forces related to the vertical temperature structure and by mechanical disturbances caused by surface roughness. *Atmospheric stability* is a measurement of turbulence effected by the thermal gradient component. *Stability categories* are qualitative classifications designated by letters of the alphabet. Class A is the most unstable and class G the most stable. The atmosphere is stable when the temperature increases with height and the vertical mixing of air (hence, the upward spread of pollutants) is inhibited. An *unstable atmosphere* implies a decrease in temperature with height, which enhances vertical mixing.

Generally, the *worst-case* stability that can occur during the day (when peak-hour traffic flow generally occurs) is class D. Even at night, class D is generally the most stable condition expected in urban areas. This is usually the case when skies are overcast in urban or rural areas, but it also occurs in urban and suburban areas on calm, clear nights when rural areas experience very stable conditions. This decreased stability in urban areas is due to heat island effects and increased surface roughness. The atmosphere is slightly unstable (class C) or neutral (class D) to a height several times that of the surrounding buildings. *Thus, these guidelines assume an atmospheric stability of class D as the worst case condition in an urban area.*

Mechanical turbulence is caused by rough terrain or by man-made obstructions to otherwise smooth wind flow. This mechanical turbulence increases dispersion of ground-level emissions. Manmade obstructions include buildings and vehicles. Moving vehicles can cause mechanical turbulence and enhance the dispersion of their own emissions. To account for this, the hot spot verification procedures employ an initial vertical dispersion parameter, σ_{zo}, of 5 meters, a typical value for urban and suburban locations where the source (roadway) is within 10 building heights of the nearest building. The screening procedures, on the other hand, use a more conservative value of 1.5 meters for σ_{zo}.

The ground-level pollutant concentrations resulting from emissions at a given source are inversely proportional to the wind speed. As wind speed increases, the emissions from a continuous source are introduced into a greater air volume per unit time. The highest CO concentrations will occur when the wind speed is low. A wind speed of 1 m/sec has been assumed as the worst-case condition here.

Carbon monoxide concentrations diminish rapidly with distance from the emission source. For the purposes of hot spot verification, the receptor is assumed to be located at the centerline of adjacent sidewalks or at the roadway right-of-way limit if no sidewalk exists.

The horizontal wind direction is usually the factor that most strongly affects pollutant concentrations at a given receptor, since the bulk transport is downwind. It is assumed in the hot spot procedure that the wind is at the angle to the roadway that yields the highest CO concentration at the receptor site.

Once the roadway/receptor separation distance is specified and the worst-case conditions are assumed, a normalized concentration term, $\chi u/Q$, can be determined. The *normalized concentration* ($\chi u/Q$) is the product of the concentration and wind speed, divided by the emission rate. Units are m^{-1}. The normalized concentration is a measure of the dilution of the contaminant due to turbulent mixing. The worst expected CO concentration resulting from vehicle emissions on the roadway is obtained by multiplying the normalized concentration term by the emission rate and dividing by wind speed (assumed to be 1 m/sec).

In the hot spot techniques, normalized concentration contributions from both free-flow and excess emissions (due to queueing at intersections) are obtained from graphs. These are corrected for roadway/receptor separation distance, then multiplied by the corresponding emission rates to obtain the concentration contributions from free-flow traffic and delayed traffic. The sum of these contributions is the total CO concentration resulting from vehicle emissions in the vicinity of an intersection, while only the free-flow emissions are needed to estimate midblock or uninterrupted flow conditions.

At certain locations in urban areas, the wind circulation patterns between tall buildings may form a vortex. These conditions may exist in areas called *street canyons*, which are characterized by specific building height and separation relationship as discussed in Section IV.B.1. Diffusion characteristics in street canyon situations are somewhat different from those where a vortex does not form. As a result, special consideration must be given to street canyons in the analysis of hot spots. These special requirements are also discussed in Section IV.B.1.

E. DETERMINING THE CRITICAL SEASON

As was discussed previously, local carbon monoxide concentrations are a function of emission rates (traffic conditions) and meteorological conditions. To determine the "critical seasons," the time of the year with the greatest potential for high carbon monoxide concentrations, one is interested in periods when high emission rates and poor dispersive conditions occur together. Choosing the critical season is important for hot spot analysis for two reasons. First, the screening and verification inputs appropriate for the critical season should be used in order to obtain worst case estimates. Second, a number of parameters, especially the correction factors, are sensitive to ambient temperature and vehicle model-year distribution, both of which are directly related to the season of the year.

The simplest method of determining the critical season is to review monitoring data to determine when the highest concentrations usually occur. In a broad sense, only a quick review of the data is required. In practice, some care must be exercised in choosing data for review to insure it will be consistent with the purpose of choosing the critical season for hot spot evaluations. In this regard, the data should be from sites that are representative of general trends at hot spot locations and not from sites that are designed to monitor background or regional levels. The EPA publication on monitor siting, OAQPS No. 1.2-012,[12] and especially Supplement A,[13] which is devoted to CO siting in particular, offer guidance as to what general types of sites are suitable (also see Reference 14). These site types are designated in Supplement A as "peak street canyon, peak neighborhood, average street canyon, and corridor." The reader who is familiar with these Hot Spot Guidelines should be able to judge the suitability of sites falling in the above types for use in determining the critical season.

Problems that may arise include inappropriate monitor sites, inadequate quantities of data, no data at all, or local anomalies causing inconsistent identification of worst case season. A solution to the first three of the problems is to apply verification procedures at a trial location using seasonal traffic and meteorological data to identify the time of year that produces the highest estimated concentrations. As an alternative, it would be better to obtain data from a similar city or town within the same geographic area and to use these data to identify the critical season. Such data would, again, implicitly contain the joint effects of traffic and meteorology. In addition, although the actual magnitudes of high CO concentrations may be different (if data were available at the location of interest to make the comparison), the important aspect is that the highest values at both locations will tend to occur during the same time of year.

The last problem area identified above, that of local anomalies, must be dealt with on a case-by-case basis. In some instances an investigation into the details of the actual monitor locations may be necessary to identify why differences occur in seasonal peaks at different sites. For example, a monitor sited near a drive-in theater that operates during the summer months only may identify (erroneously from an overall hot spot evaluations viewpoint) summer to be the critical season. The local air pollution control agency should be helpful in making these determinations.

F. EXAMPLE

This example is provided to illustrate some of the concepts discussed in this section and in subsequent sections. In this section, one location is introduced and described with regard to its operational and environmental characteristics. The information presented here is input data to the example that continues in the hot spot screening (Section III.D) and the verification (Section IV.D).

The Lexington Street - School Street intersection in Waltham, Massachusetts has been selected for the example. Figure 5 provides a sketch of the location. This signalized intersection is located on the northern fringe of the central business district. Lexington Street is the major arterial connecting the northern portion of the city with the central core. School Street, a minor arterial, parallels Main Street, the major arterial through the CBD, and serves as a bypass to circumvent the CBD traffic congestion. Because of its proximity to the CBD, vehicular traffic levels through the intersection are uniform most of the day.

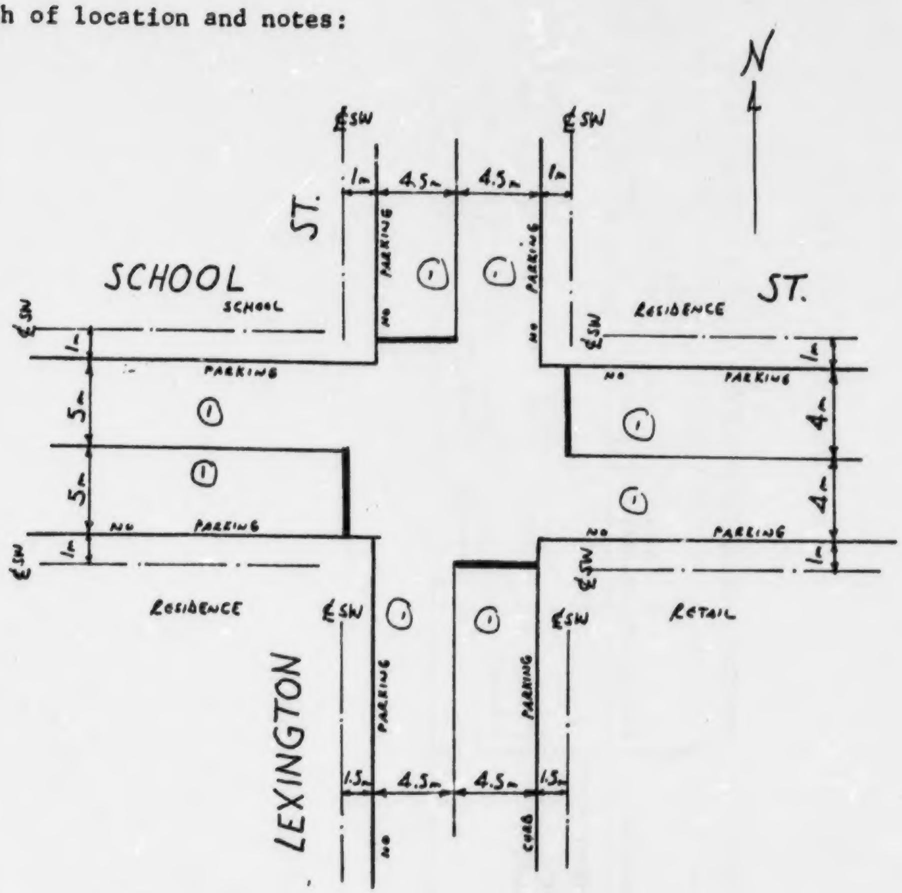
Both streets operate as 2-lane, 2-way facilities with parking permitted only on the east side of Lexington Street's south approach and the north side of School Street's west approach. The intersection is controlled by an isolated fixed time signal controller. These general characteristics are summarized in Table 2.

The signal phasing and timing is presented in Table 3. The total cycle length is 60 seconds, with 32 seconds allocated to the green phase for Lexington Street and 20 seconds for School Street. The remaining 8 seconds

City/Town: Waltham, Ma By: TPM

Location: Lexington St. @ School St. Date: 26 Sep '75

Sketch of location and notes: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5m
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1m
NO PARKING
NO PARKING
RESIDENCE
RETAIL
℄SW
℄SW
LEXINGTON
NO PARKING
PARKING
1.5m
4.5m
4.5m
1.5m
CURB

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) Est. departure cruise speed is 15 mph

5) Traffic signal controls

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Figure 5. Sketch of Lexington Street-School Street Intersection

Table 2. TRAFFIC CHARACTERISTICS OF EXAMPLE INTERSECTION

Intersection: approach	Description	Street classification	Curb parking	Roadway width, m	G/Cy	ADT, 1977	Peak hour traffic, % ADT	Cruise speed, mph
School Street at Lexington Street								
Lexington Street North	2-lane 2-way	Major arterial	None	9	0.53	14,000	6.5	15
Lexington Street South			east side	9	0.53	10,000	6.5	15
School Street East		Minor arterial	None	8	0.33	8,000	6.5	15
School Street West			north side	10	0.33	9,000	6.5	15

Table 3. SIGNAL PHASING AND TIMING AT EXAMPLE INTERSECTION

Signal facing	Signal indication			
Lexington Street	G	Y	R	R
School Street	R	R	G	Y
Time, seconds	32	4	20	4

Table 4. EMISSION CORRECTION FACTOR CHARACTERISTICS OF EXAMPLE INTERSECTION

Vehicle mix distribution	
LDV	78%
LDT	11%
HDV-G	6%
HDV-D	5%
Vehicle operating mode distribution	
Cold start	10%
Hot start	10%
Stabilized	80%
Ambient temperature	30°F

are split between the two streets for their respective yellow clearing phases. The signal timing equates to a G/Cy of 32/60 or 0.53 for both Lexington Street approaches and to a G/Cy of 20/60 or 0.33 for both School Street approaches. Recall that the G/Cy assigned to an approach is a function of the critical volume demand on that approach and the demand on that approach plus the demand on the cross street approach. Quantitatively it can be expressed as:

$$\frac{G/Cy_1}{\left(G/Cy\right)_1 + \left(G/Cy\right)_2} = \frac{ADT_1}{ADT_1 + ADT_2}$$

Substituting the data provided in Table 2 for this intersection, the following results:

$$\frac{0.53}{0.33 + 0.53} = 0.62 \qquad \frac{14{,}000}{9000 + 14{,}000} = 0.61$$

The allocation of the green time to the approaches is thus shown to be distributed most efficiently.

The average daily traffic (ADT) ranges from a high of 14,000 veh/day to a low of 8,000 veh/day as shown in Table 2. A vehicle classification count at this intersection determined the distribution of the vehicle type using the facility. These data are presented in Table 4. The peak-hour traffic volume is approximately 6.5 percent of the total daily volume, and the directional distribution for each approach is approximately 50 to 50. The peak-hour directional traffic volume for any approach is the product of the ADT, the fraction of the ADT occuring during the peak hour, and the directional distribution. The peak-hour traffic volume entering the intersection from the north approach of Lexington Street is computed as:

$$(14{,}000)(6.5\%)(50\%) = 455$$

The peak-hour volume for the other approaches would be computed similarly. Other factors discussed in this chapter will be added to the analysis of Lexington Street at School Street in later sections of the guidelines.

SECTION III

HOT SPOT SCREENING

A. INTRODUCTION

The screening procedures presented in this report are based on techniques developed previously for estimating carbon monoxide concentrations in the vicinity of indirect sources.[15,16] Before presenting these procedures, a general discussion of their purpose and technical basis are in order.

1. Purpose of Screening

The screening process can be defined as a preliminary investigation of an area to identify specific locations where carbon monoxide concentrations may exceed the NAAQS. With respect to highway networks, the highest concentrations of carbon monoxide typically occur in the vicinity of intersections where vehicle speeds are low and much vehicle acceleration, deceleration and idling takes place. Concentrations along limited access highways or at midblock locations on arterial streets may also exceed the NAAQS, therefore these locations must be considered in the screening process as well. Owing to major differences in emission characteristics - and hence in pollutant concentrations - separate screening techniques were developed for highway intersections and midblock locations. Also, emission characteristics of intersections will vary substantially depending on whether or not traffic signals are utilized, therefore separate procedures were also developed for both signalized and nonsignalized intersections.

2. Screening Concept

Inasmuch as the effort here was directed toward development of a general guideline for identifying carbon monoxide hot spots, consideration was given to several issues that will have an influence on the methodology utilized. First, in effect, the guidelines will be used to evaluate literally hundreds of street sections and intersections within any municipality; therefore, the parameters considered must be general enough to require the absolute minimum of data input, yet the process must yield a reliable assessment of hot spot potential. Second, the process should be relatively simple and capable of being accomplished quickly, utilizing data that is ordinarily available from state or city agencies. Third, the process should be applicable (with perhaps minor modifications) to any city or town where the existence of hot spot problems is suspected. These factors, plus the fact that traffic operating characteristics are often highly varied among similar locations (for example, among signalized intersections), indicated that the screening process should involve a very general approach, relying to a great extent on the validity of applying an assumed set of conservative parameters in order to reduce to a minimum the number of variables that must be considered in the process.

In general, then, the screening process involves establishing a relationship between air quality and several general traffic operating characteristics within the vicinity of an intersection or midblock section, based on information provided in the Indirect Source Guidelines.[16] The need for further analysis of a particular location will then be based on whether a potential air quality problem is indicated by the screening procedure.

Two standards exist for maximum carbon monoxide concentrations - the first, 40 mg/m^3 (35 ppm) applies to a 1-hour average concentration, while the second, 10 mg/m^3 (9 ppm), applies to an 8-hour average concentration. For most highway applications, the 8-hour standard is most often violated, therefore, the screening process focuses on the 8-hour average concentration.

3. Assumptions and Limitations

The implied relationship between air quality and traffic operating characteristics actually is a relationship between air quality and emissions intensity. In the vicinity of highways, emissions intensity depends on parameters such as traffic volume, emission characteristics of the vehicle fleet, quantitative and qualitative operating characteristics (capacity and level of service) of the roadway or intersection, and the actual orientation from the emissions source (e.g., the distance from and height above the traffic lane). Also contributing to the emissions intensity at any location is the background concentration that results from extra- and intraurban diffusion of the pollutant (carbon monoxide), and the prevailing meteorological conditions (macroscale and microscale).

Of the parameters outlined above, capacity and volume characteristics will vary most significantly among locations, while it can be assumed that the other parameters are constant throughout an area. Therefore, the screening process is based on an air quality-emissions intensity relationship where emissions intensity is the independent variable and, also, where emissions intensity is considered to be a function of two variables - volume demand and traffic flow characteristics - and a constant set of factors to account for the vehicle-fleet emissions characteristics, orientation and distance from the source, background concentrations, and prevailing meteorology.

In developing the screening procedures, a distinction was made between (1) the factors that influence CO levels and are site-specific and (2) the factors that do not vary significantly from one site to another. Of the factors mentioned in Section II, the highly site-specific elements are traffic operational characteristics such as volume and vehicle speeds. Each of these is thus determined separately for each location to be screened. Several other factors are assumed to be common to an area for a worst case analysis such as the composite emission factors, and meteorological factors. In summary, the screening procedure uses (1) a standardized set of meteorological conditions, (2) a standardized set of emission factors, and (3) data on traffic operational conditions for each site to be analyzed.

Because the purpose of the screening procedure is to efficiently identify possible hot spot locations, it was necessary to include a number of simplifying assumptions in the procedures. Where such assumptions were made and where generalized conditions or relationships were included, they were done so conservatively; that is the screening process is designed to overstate possible CO levels rather than underestimate them in order to insure that potential hot spots will not be missed. Each succeeding stage of analysis has fewer assumptions, however. The screening requires the least effort per site and thus has the greatest number of simplifying assumptions. Verification allows a greater number of localized adjustments and thus is more accurate; however, it requires greater effort per site, but need only be performed for sites shown by screening to have hot spot potential. Detailed computer modeling, not presented in this volume, requires the greatest effort for each site and is the most flexible technique for handling all variables.

a. Meteorological Assumptions - To simulate worst case conditions, the screening procedure assumes a constant low windspeed (1 meter/sec or 2 mph) for all locations. These conditions are reasonable for most areas as can be seen in climatological records. As for wind direction, the procedure assumes that the wind is at an angle to the roadway that tends to produce the highest concentrations of CO. This assumption eliminates the need to analyze seasonal wind direction frequencies separately for each intersection or midblock location to be analyzed. These assumptions are conservative because any given location will tend to experience every wind angle during a year.

Another meteorological factor is ambient temperature. Inasmuch as the peak CO concentrations tend to occur in the winter, and assumed ambient temperature of 0°C (32°F) is reflected in the screening procedure. Colder temperatures produce higher emission rates, and temperatures colder than

0^oC are certainly not uncommon.* The value 0^oC was selected, however, because it is perhaps representative of the range in winter afternoon temperatures experienced throughout much of the U.S.

Additional assumptions are that stability category D prevails and that the initial vertical dispersion parameter has a value of 1.5 meters. These parameters were discussed in the previous section.

b. Traffic Assumptions - To minimize the need for collection of special traffic data, the screening procedures were designed to use average daily traffic (ADT) as the primary input. ADT statistics are generally available for the primary streets in most regions from traffic engineering or planning agencies. Implicitly, the screening procedure utilizes several assumptions concerning hourly traffic distribution, lane distribution, and vehicle-type distribution. Specifically, these assumptions are that:

- peak hour traffic represents 8.5 percent of the ADT;
- the directional split on midblock sections of arterials and on expressways is 50 percent and 50 percent; at intersections, the split is 50 percent and 50 percent;
- for multilane facilities, the volume of the outside lanes (shoulder lanes) is equal to the inner lane volume; and
- the traffic stream is comprised of 88 percent LDV, 8 percent LDT, 3 percent HDV-G, and 1 percent HDV-D.

Again, each of these assumptions is judged to be reasonable for screening purposes. As for verification, there is a provision for determining actual hourly volumes. In both cases, there are additional assumptions regarding signal operations and speed-volume-capacity relationships, which are discussed elsewhere in this report.

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*As an example, the mean daily average temperature in Boston is 30^oF in in January and February, which indicates there are many hours with temperatures below the assumed 32^oF; also there are 94 days per year in Boston during which the minimum temperature is 32^oF or below.

c. General Assumptions - The screening procedures are based upon the 1982-1983 winter period; that is, the assumed vehicle population has the emission characteristics of that time. This period was chosen because a primary objective of the procedures outlined in these guidelines is to identify locations where CO levels may exceed the NAAQS after the mandatory compliance data, which is December 1982. Again, the highest ambient concentrations are usually expected to occur during the winter months, therefore it is appropriate that conditions during the winter months subsequent to the mandatory compliance data be reflected in the procedures presented here.

A further assumption concerns receptor orientation with respect to the roadway. Throughout the screening procedure, it is assumed that the receptor is located along a line offset from the edge of the traveled way by 5 meters at intersections and 10 meters at other locations.

d. General Comments - The procedures described here embody a number of simplifying assumptions, the most important of which have been described. Such simplifications are necessary to keep the screening process simple, and these assumptions will apply more accurately to some locations than to others. The user should recognize that the assumed conditions will not be representative of conditions at all locations, but, overall, the procedures will produce a reasonable estimate of peak CO concentrations. Again, the assumed general conditions were chosen to be conservative in order to prevent overlooking hot spots. Later stages of the overall hot spot analysis are more site-specific, less conservative, and thus more accurate. The screening process is by design qualitative, and will only identify those sites with the potential for violations of the NAAQS.

B. OVERVIEW OF THE SCREENING PROCEDURE

A description of the screening procedure must include discussion of three critical elements, viz: (1) the data required, (2) the nomographs that relate the roadway and traffic operating characteristics to air quality, and (3) a set of standard worksheets on which the input data and the results of the analysis are recorded. Each of these elements is described below.

1. Data Requirements

The entire screening procedure may be possible to complete for many communities with only a minimal field data collection effort. Data required include areawide traffic volume data and a street inventory of sufficient detail to indicate the lane composition (use and number of lanes), traffic control utilized (mainly, the locations of signalized intersections are of primary importance), and whether various streets operate one-way or two-way, and whether or not congested conditions normally prevail. Also, additional backup data are required to estimate the lane capacity of arterial streets and expressways, as will be mentioned later. The data required for hot spot screening for signalized intersections, nonsignalized intersections, and arterials and expressways are summarized in Table 5.

a. Traffic Volume Data - Traffic volume data should be summarized in the form of a traffic flow map indicating the highest monthly average daily traffic (ADT) volumes for the winter season, reflecting the 1982-1983 period. Volumes can be adjusted by the application of annual growth factors. Volume data need not be developed for every street on the network; of primary interest should be: (1) those streets and highways on the Federal Aid System, (2) those not on the Federal Aid System but that are controlled by traffic signals; and (3) those not on the Federal Aid System but that are considered by local officials to be "important" or high volume facilities.

Traffic volume is perhaps the most abundant data element available concerning a highway network. The intent here is that existing data be used wherever possible, implying that existing volume data should be available in most instances to develop a suitable traffic flow map. In many communities where traffic studies or transportation plans have been developed, flow maps may already be available requiring only minimal updating.

Table 5. SUMMARY OF DATA REQUIREMENTS FOR HOT SPOT SCREENING

Signalized Intersections

- Location of signalized intersections.
- Street inventory to determine lane use and number and directional operation of intersection approaches.
- Volume data (ADT) for all intersection approaches.

Nonsignalized Intersections

- Location of signed control intersections.
- Street inventory to determine lane use and number and directional operation of intersection approaches.
- Volume data (ADT) for all intersection approaches.
- Lane capacity on major through street

Uninterrupted Flow

- Location and number of lanes of expressway and arterials of uninterrupted flow.
- Volume data (ADT) for the facility
- Roadway lane capacity

Development of flow maps, however, should be carefully guided by cognizant highway and transportation planning officials.

b. Highway Inventory Data - Highway inventories are normally available from state transporation, planning or highway departments. These inventories should be made available for each community where hot spots are being investigated. The required data that can be obtained from these inventories include descriptions of operational characteristics of the roadways (e.g., one-way or two-way operation); information regarding the number of lanes, use of medians, functional classification, etc., and occasionally, volume data. Also, data must be obtained regarding intersectional traffic control, particularly the locations where traffic signals are utilized. It is helpful if the locations of all signalized intersections are plotted on a base map.

c. General Backup Data - Other data elements are required that may not be available from previous studies or from existing inventories. Included is information required to estimate the lane capacity of streets on the network, mainly, estimates of truck factors, knowledge of conditions such as restricted lateral clearances, severe terrain features, etc. This information can be obtained through local planning or engineering personnel and by field reconnaissance. For a comprehensive discussion of roadway lane capacity, the reader is referred to the Highway Research Board's Special Report No. 87, the 1965 Highway Capacity Manual.[9] A methodology for calculating capacities based on this document is presented in Section III.D of these guidelines.

2. Definitions

Several terms used in the screening procedure are defined below.

a. *Complex Intersection* - This term refers to a signalized intersection that, because of volume demand, turning movements, geometry, number of approaches, etc., requires three or more signal phases. Also, an intersection characterized by very heavy pedestrian activity as well as high volumes on all approaches may be considered a complex intersection. Complex intersections cannot be appropriately analyzed using the screening procedure.

b. *Special Case* - A special case refers to either a signalized or nonsignalized intersection where conditions are such that, again, the screening procedure is not appropriate for evaluating hot spot potential. Examples of special cases include (1) signals used only for certain events such as during peak-hour only, or during work-shift changes if the location is in the vicinity of a major industrial or office complex; (2) where signals are manually operated or preempted in favor of traffic direction by police personnel; (3) where signals are utilized for pedestrian crossing protection only; and (4) where police control is utilized at nonsignalized intersections.

c. *Congested/Noncongested Areas* - These terms are utilized in the screening procedure to indicate whether or not significant interference to traffic departing from an intersection can be expected. For congested areas, downstream cruise speeds will be fairly low (less than about 20 miles per hour) with some interruptions occurring. In noncongested areas, however, few if any interruptions to departing traffic will occur, and downstream cruise speeds will be somewhat higher (at least 25 miles per hour).

3. Nomographs for Hot Spot Screening

The nomographs for screening provide the basic tool for relating various traffic and roadway characteristics to hot spot potential. In particular, these nomographs relate a roadway's average daily volume demand and capacity characteristics to potential for exceeding the National Ambient Air Quality Standard for 8-hour average concentrations of carbon monoxide (10.0 mg/m^3 (9.0 ppm)). Hot spot potential is indicated when the respective ADT's for any particular street under analysis and cross street are plotted on the nomograph and the point plotted falls on or above the curve. The use of the nomographs is explained in detail in the following paragraphs. Separate sets of nomographs are presented for three distinct types of street locations including signalized intersections, nonsignalized intersections, and for conditions where uninterrupted flow prevails. Each of these is discussed below.

a. Signalized Intersections - Ten separate nomographs are presented. Each of the nomographs was developed for screening intersection approaches of a particular configuration. Included are nomographs developed for screening:

- 2-lane, 2-way (congested area)
- 2-lane, 2-way (noncongested area)
- 3-lane, 2-way (congested area)
- 3-lane, 2-way (noncongested area)
- 4-lane, 2-way (congested area)
- 4-lane, 2-way (noncongested area)
- 3-lane, 1-way (congested area)
- 3-lane, 1-way (noncongested area)
- 2-lane, 1-way (congested area)
- 2-lane, 1-way (noncongested area)

A series of five curves appears on each nomograph. Each of these curves represents a particular configuration of the cross street (with respect to the approach being screened). Curves representing the following cross street configurations are plotted on each nomograph:

- 2-lane, 1-way
- 2-lane, 2-way
- 3-lane, 1-way
- 3-lane, 2-way
- 4-lane, 2-way

Each of the curves is a plot of the ADT on the intersection approach under analysis (abscissa) versus the ADT on the cross street (ordinate).

Each point on any of the curves, then, represents that combination of traffic volumes (on the street under analysis and the cross street) which, under certain assumed conditions, would result in ambient carbon monoxide concentrations at or very close to the 10.0 mg/m^3 permitted by the National Ambient Air Quality Standard for 8-hour average concentrations. These assumed conditions include a maximum distribution of the available green time between the street under analysis and the cross street,[*] which accounts for the finite limits of the plotted curves on the nomographs. Also assumed is that there is a background concentration present, which comprises 2.9 mg/m^3 of the implied 10.0 mg/m^3 concentration. *If the respective ADT's for any particular configuration of street (under analysis) and cross street are plotted on the nomograph and the point plotted falls on or above the (cross street) curve, the implication is that resulting carbon monoxide concentrations are potentially in the vicinity of 10.0 mg/m^3 or more, indicating that the approach has hot spot potential.* Plotting the ADT's (for winter 1982-1983) in this manner and noting where the plot lies with respect to the cross street curve, is essentially the entire procedure involved for using the nomographs. The appropriate nomograph is selected based on the configuration of the approach being analyzed while selection of the appropriate curve on the nomograph is based on the cross street configuration.

b. Uninterrupted Flow - Two types of locations are considered where conditions of uninterrupted flow prevail - these include expressways (controlled access) and arterial streets. One nomograph is presented for each of these two facility-types.

On the nomograph for expressways, three separate curves are plotted representing 4-lane, 6-lane, and 8-lane expressways. These curves are plotted as lane capacity (abscissa) versus ADT (ordinate). Each point on the curve represents that combination of lane capacity and 24-hour volume that, under certain assumed conditions, would result in nearby ambient carbon monoxide concentrations of approximately 10.0 mg/m^3. The implication, again, is that for a particular roadway configuration with a certain lane capacity, *an ADT equal to or in excess of the "critical" ADT (shown by the curve on the nomograph) indicates that the location may be a potential hot spot.*

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[*] The G/Cy allocated to the street under analysis ranges from 0.20 to 0.80 representing the top left and bottom right extremities of the nomograph curves, respectively. Recall that G/Cy is directly related to ADT and that each approach must be allotted a minimum G/Cy.

A similar nomography is presented for arterial streets showing the critical ADT for various lane configurations. *Again, if the actual ADT (estimated for winter 1982-1983) exceeds the "critical" ADT, hot spot potential is indicated.*

The procedure, then, for using either of the nomographs is to plot the estimated lane capacity versus its ADT and observe where this plot lies with respect to the curve corresponding to the facility's configuration - if the plot falls on or above the curve, hot spot potential is indicated.

c. Nonsignalized Intersections - Ten separate nomographs have been developed for the screening of nonsignalized intersections. These nomographs are utilized to screen intersection approaches controlled by STOP-signs only; the through street approaches of a STOP-sign controlled intersection are screened utilizing the nomographs presented for uninterrupted flow.

Each nomograph contains a curve representing the combination of ADT's on the street under analysis and the through-street that would result in ambient carbon monoxide concentrations of approximately 10.0 mg/m^3 (assuming certain other conditions prevail). Therefore, in order to use these nomographs, two data elements other than the configuration of each street approach must be determined, including (1) the ADT (winter 1982-1983) on the street under analysis, and (2) the ADT (winter 1982-1983) on the major through street. *If, then, the ADT's are plotted and the point lies on or above the curve corresponding to the lane capacity of the major approach, hot spot potential is indicated.*

Selection of the nomograph is based on the configuration of both the STOP-sign controlled street being analyzed and the major through street. Nomographs were developed for the screening of the following STOP-sign controlled street configurations:

- 2-lane, 2-way minor; 2-lane major (congested area)
- 2-lane, 2-way minor; 2-lane major (noncongested area)
- 2-lane, 2-way minor; 4-lane major (congested area)
- 2-lane, 2-way minor; 4-lane major (noncongested area)
- 4-lane, 2-way minor; 4-lane major (congested area)
- 4-lane, 2-way minor; 4-lane major (noncongested area)
- 2-lane, 1-way minor; 2-lane major (congested)
- 2-lane, 1-way minor; 2-lane major (noncongested)
- 2-lane, 1-way minor; 4-lane major (congested)
- 2-lane, 1-way minor; 4-lane major (noncongested)

4. Hot Spot Screening Worksheets

Presented in the following pages are standard worksheets to be used for performing and reporting the screening of a street network. Included are:

- Hot Spot Screening Summary Sheet - Worksheet 1
- Screening Worksheet-Signalized Intersections - Worksheet 2
- Screening Worksheet-Nonsignalized Intersections - Worksheet 3
- Screening Worksheet-Uninterrupted Flow - Worksheet 4

a. Screening Summary Sheet (Worksheet 1) - This form, as its name implies, is intended to be used for summarizing the hot spot screening effort for a community. The information to be entered on the sheet includes:

1. A description of each location analyzed - Broadway at Park Street, or Vasser Street between Parson's Road and Kennelworth Drive, for example.
2. The type of location analyzed - either signalized intersection, nonsignalized intersection, freely flowing arterial section, or expressway.
3. Whether or not hot spot potential is indicated by the analysis.

The locations listed are then numbered sequentially.

b. Screening Worksheet - Signalized Intersections (worksheet 2) - This worksheet provides space for the analysis of two separate intersections. To complete this form enter the intersecting streets named in Part I, and indicate whether or not the intersection is located in a congested area in Part II. (A congested area implies cruise speeds of less than 20 mph). In Part III, it is indicated whether or not the location should be considered a complex intersection (unusual geometery) or a special case. For locations that are not considered complex intersections or special cases, the actual screening is performed in Part IV.

In Part IV each approach to the intersection is analyzed separately. Under the main column heading "Approach Under Analysis," the approach designation (name and orientation such as Amity Road, south approach), the adjusted (i.e., projected 1982) average daily traffic volumes, and the roadway configuration (for example, 4-lane, 2-way) are entered.

Under the other main column heading of "Cross-Street Data," the appropriate data elements for the cross street approach having the highest traffic volume are recorded. Then, utilizing the appropriate nomograph and curve, a determination of hot spot potential is made and recorded. If the configuration of the other approach of the cross street is different from the approach previously used in the analysis, the procedure is repeated using the data for the second cross-street approach and the appropriate nomograph and curve. Note that columns f and j provide space to record the figure number and curve designation for the nomograph used to perform the screening.

c. Screening Worksheet - Nonsignalized Intersections (Worksheet 3) - This worksheet allows for the analysis of four nonsignalized intersections. In the first major column, the through street is analyzed in the same fashion as for uninterrupted flow conditions. Each approach of the controlled cross street is then analyzed in the two columns under the heading of "Cross-Street Data."

d. Screening Worksheet - Uninterrupted Flow (Worksheet 4) - Up to 30 locations where conditions of uninterrupted flow prevail can be analyzed on each of these worksheets. The data required include the facility name; a description of its location; its volume, configuration, and capacity, and finally, whether or not hot spot potential is indicated.

5. Performing Hot Spot Screening

Detailed instructions on performing hot spot screening are provided in Section III.C which follows. Prior to this detailed discussion it may be helpful to look at the process in general terms; this can be best illustrated by a flow diagram as shown in Figure 6.

As can be seen from the flow diagram, the first steps involve compiling the required data. Once this has been completed, screening begins. First, all signalized intersections are screened, followed by locations where uninterrupted flow prevails, and finally, nonsignalized intersections. The importance of the order of analysis becomes apparent in the following detailed discussion.

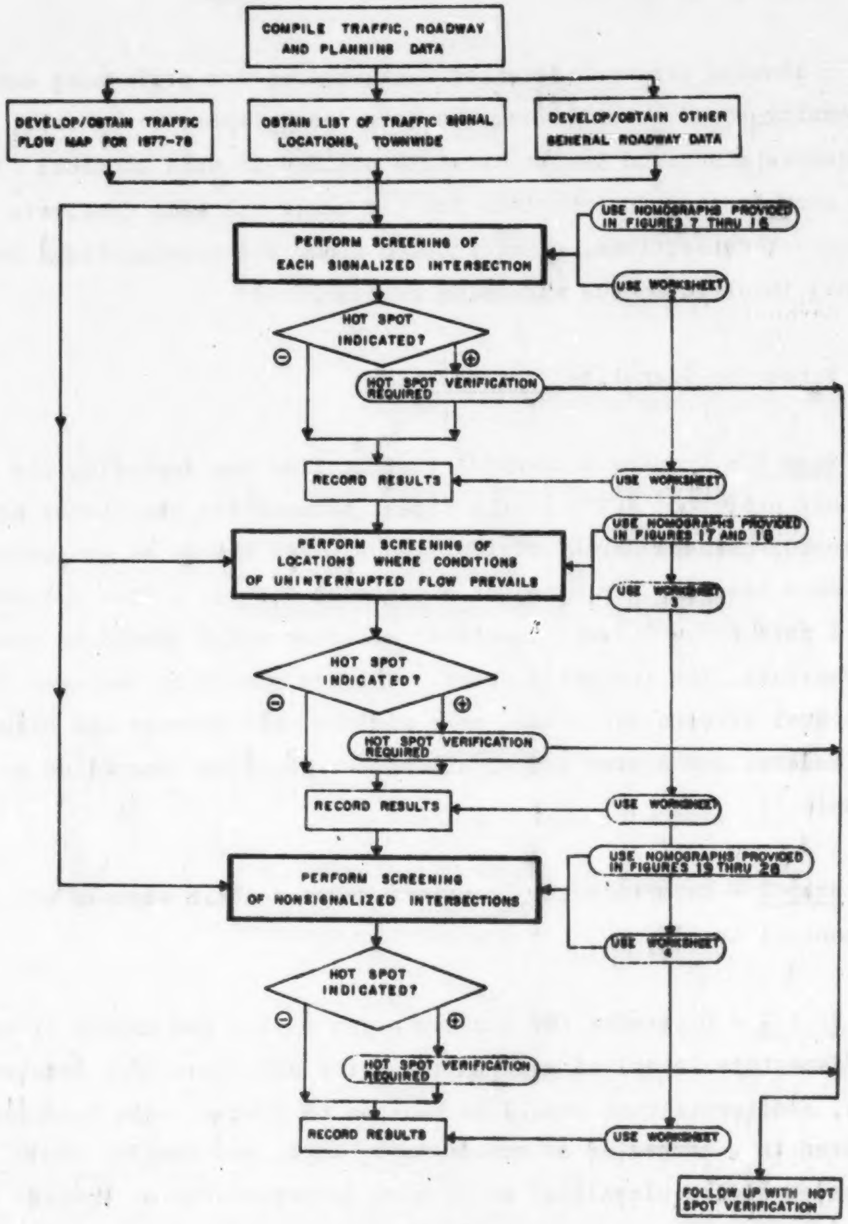
COMPILE TRAFFIC, ROADWAY AND PLANNING DATA
DEVELOP/OBTAIN TRAFFIC FLOW MAP FOR 1977-78
OBTAIN LIST OF TRAFFIC SIGNAL LOCATIONS, TOWNWIDE
DEVELOP/OBTAIN OTHER GENERAL ROADWAY DATA
PERFORM SCREENING OF EACH SIGNALIZED INTERSECTION
USE NOMOGRAPHS PROVIDED IN FIGURES 7 THRU 16
USE WORKSHEET 2
HOT SPOT INDICATED?
⊖
⊕
HOT SPOT VERIFICATION REQUIRED
RECORD RESULTS
USE WORKSHEET 1
PERFORM SCREENING OF LOCATIONS WHERE CONDITIONS OF UNINTERRUPTED FLOW PREVAILS
USE NOMOGRAPHS PROVIDED IN FIGURES 17 AND 18
USE WORKSHEET 3
HOT SPOT INDICATED?
⊖
⊕
HOT SPOT VERIFICATION REQUIRED
RECORD RESULTS
USE WORKSHEET 1
PERFORM SCREENING OF NONSIGNALIZED INTERSECTIONS
USE NOMOGRAPHS PROVIDED IN FIGURES 19 THRU 28
USE WORKSHEET 4
HOT SPOT INDICATED?
⊖
⊕
HOT SPOT VERIFICATION REQUIRED
RECORD RESULTS
USE WORKSHEET 1
FOLLOW UP WITH HOT SPOT VERIFICATION

Figure 6. Process flow diagram for the screening of carbon monoxide hot spots

C. DETAILED INSTRUCTIONS FOR HOT SPOT SCREENING

The following presents detailed instructions for performing hot spot screening based on utilizing the data, nomographs, worksheets, and general procedure discussed in the previous portion of this section. Included are step-by-step instructions for the three subtasks (analysis of signalized intersections, uninterrupted flow, and nonsignalized intersections) involved in the screening process.

1. Screening Signalized Intersections

a. Step 1 - Prepare a townwide traffic flow map depicting the highest monthly projected ADT's on the street network for the winter months (November through March) of 1982-1983. This should be presented on a suitable base map (or maps) at a scale of between 1 inch = 1,000 feet and 1 inch = 3,000 feet; insets at a larger scale should be used, as appropriate, for congested areas. Volumes should be included for all principal streets including, as a minimum, all streets and highways on the Federal Aid System and on all street sections controlled by traffic signals.

b. Step 2 - Determine the locations where traffic signals are utilized to control traffic.

c. Step 3 - Determine the configuration (i.e., the number of approach and departure lanes) of each approach for all signalized intersections. Also, a determination should be made as to whether each intersection is located in a congested or noncongested area, and whether any of the locations should be classified as complex intersections or special cases (unusual geometry or unusual signal control such as by a police officer).

d. Step 4 - Enter appropriate data for each signalized intersection on the Screening Worksheet - Signalized Intersections (see Worksheet No. 2) as follows:

1. Part I:
    a. Enter the location (e.g., Main Street at Naussam Road).
2. Part II:
    a. Record whether or not the location is generally within a congested area.
3. Part III:
    a. Record whether or not the location should be considered a complex intersection or special case (see definitions on pages 49 and 50). If it is either a complex intersection or a special case, enter the location on the Hot Spot Screening Summary Sheet (Worksheet No. 1) and proceed to the next intersection.
    b. If the location is neither complex nor a special case, proceed to Part IV.
4. Part IV: Each approach of the intersection is analyzed as follows:
    a. Enter the approach designation (e.g., Main Street, south approach) in column a. It is important to identify the particular approach being considered (e.g., Main Street, south approach).
    b. Enter the adjusted ADT (winter 1982-1983) in column b.
    c. Enter the configuration (e.g., 2-lane, 1-way) of the approach in column c.
    d. Enter the name and orientation (e.g., Main Street, east approach) of each cross street approach on the line above columns d through k.
    e. For the first approach of the cross street:
        1. Enter the adjusted ADT (winter 1982-1983) in column d.

2. Enter its configuration (e.g., 2-lane, 1-way) in column e.

3. Enter the figure number and curve to be used for screening in column f (see Section III.B.3 beginning on page 50 for instructions on the selection of figures and curves).

4. Using the figure and curve noted in column f, determine whether or not hot spot potential exists; record this determination in column g.

f. For the other approach of the cross street:

1. Enter the adjusted ADT (winter 1982-1983) in column b.

2. Enter its configuration (e.g., 2-lane, 2-way) in column i.

3. Enter the figure number and curve to be used for screening in column j (see Section III.B.3 beginning on page 50 for instructions on the selection of figures and curves).

4. Using the figure and curve noted in column j, determine whether or not hot spot potential exists; record this determination in column k.

g. *Repeat the previous steps in Part IV for each approach.*

5. After all approaches have been analyzed, enter the location on the Hot Spot Screening Summary Sheet (Worksheet No. 1); include the following data:

a. Location (street names).

b. Type (in this case, signalized intersection)

c. Whether or not a hot spot is indicated - *a hot spot is indicated if any entry in columns g or k is affirmative.*

e. Step 5 - Repeat Step 4 for all signalized intersections on the street network.

2. Screening Locations Where Conditions of Uninterrupted Flow Prevail

a. Step 1 - Identify sections of expressway (controlled access) where the following conditions prevail:

Highway configuration	ADT
4-lane highway	≥ 40,000
6-lane highway	> 50,000
8-lane highway	> 65,000

These ADT's are slightly below those that would generally have hot spot potential.

b. Step 2 - For each section identified in Step 1 as meeting the above criteria, enter the highway name or route number in column (a) of the Screening Worksheet - Uninterrupted Flow (Worksheet No.4). Also on this worksheet, enter the following data for each location:

1. Description of the location (e.g., north of the Brook's Highway Interchange) in column b.
2. The adjusted ADT (winter 1982-1983) in column c.
3. Highway configuration (e.g., 4-lane expressway) in column d.
4. Estimated lane capacity in column e (see Section III.D beginning on page 70).
5. Using the appropriate curve in Figure 17, determine whether or not the facility is a potential hot spot (for instructions on selecting the appropriate curve and use of the figure, see page 52); record this determination in column f.

c. Step 3 - Upon completion of Step 2, record the locations on the Hot Spot Screening Summary Sheet; include:

1. Facility name and location (from columns a and b of the worksheet.
2. Type of facility (in this case, expressway-uninterrupted flow).
3. Whether or not hot spot potential is indicated (from column f of the work sheet.

d. Step 4 - Identify arterial street sections on the highway network that meet the following criteria:

1. Volumes:

Highway configuration	ADT
2-lane arterial	≥ 15,000
4-lane arterial	≥ 25,000
6-lane arterial	≥ 35,000

2. Proximity to Signalized Intersections: *The section should be at least 1 mile from a signalized intersection.*

e. Step 5 - For each arterial section identified in Step 4 as meeting the above criteria, enter the street name (or other identifier) in column a of the Screening Worksheet - Uninterrupted Flow (see Section III.B.4). Also on this worksheet, enter the following data for each location:

1. Description of the location (e.g., between Marginal Way and Ober Road) in column b.
2. The adjusted ADT (winter 1982-1983) in column c.
3. Street configuration (e.g., 4-lane arterial) in column d.
4. Estimated lane capacity in column e (see Section III.D. beginning on page 70).
5. Using the appropriate curve in Figure 18, determine whether or not the facility is a potential hot spot (for instructions on selecting the appropriate curve and use of the figure, see page 52 page 52); record this determination in column f.

f. Step 6 - Upon completion of Step 5, record the locations on the Hot Spot Screening Summary Sheet; include:

1. Facility name and location (from columns a and b of the worksheet).
2. Type of facility (in this case, arterial-uninterrupted flow).
3. Whether or not hot spot potential is indicated (from column f of the worksheet.

3. Screening Nonsignalized Intersections

a. Step 1 - Identify all nonsignalized intersections where either the major street or controlled street volumes exceed the critical ADT's shown below (for various street configurations):

Street configurations		Critical ADT's	
Major street	Controlled street[a]	Major street	Controlled street[a]
2-lanes	2-lanes	10,000	2,500
4-lanes	2-lanes	20,000	2,500
4-lanes	4-lanes	20,000	8,000

[a] Under control of STOP sign.

b. Step 2 - For each intersection identified in Step 1 as meeting the above volume criteria, enter the location in Part I of the Screening Worksheet - Nonsignalized Intersections (Worksheet No.3).

c. Step 3 - For Part II of the worksheet enter the following:

1. For the major through street enter:
   a. Adjusted ADT (winter 1982-1983) in column a.
   b. Configuration (e.g., 2-lane arterial) in column b.
   c. Using Figure 18, determine whether or not hot spot potential exists on the through street (see Section III.B.3.b on page 52 for instructions on selecting the appropriate curve); record this determination in column c.
2. For the first controlled street approach enter:
   a. Street name and its orientation (e.g., Trask Lane, east approach).
   b. Adjusted ADT (winter 1982-1983) in column d.

   c. Configuration (e.g., 2-lane, 2-way) in column e.

   d. The figure number to be used for screening in column f (see Section II.B.3.c on page 53 for instructions on the selection of figures and curves).

   e. Using the figure designated in column f, determine whether or not hot spot potential exists; record this determination in column g.

3. For the second controlled street approach enter:

   a. Street name and its orientation (e.g., Trask Lane, west approach).

   b. Adjusted ADT (winter 1982-1983) in column h.

   c. Configuration (e.g., 2-lane, 1-way) in column i.

   d. The figure number and curve to be used for screening in column j (see Section III.B.3.c on page 53 for instructions on the selection of figures and curves).

   e. Using the figure and curve designated in column j, determine whether or not hot spot potential exists; record this determination in column k.

d. Step 4 - Upon completion of Step 3, record the locations on the Hot Spot Screening Summary Sheet; include:

1. Location (street names).
2. Type (in this case, nonsignalized intersection).
3. Whether or not a hot spot is indicated - *a hot spot is indicated if any entry in columns c, g, or k is affirmative.*

4. Other Locations

Other locations may be identified during the initial screening that should be analyzed for possible hot spot potential. These locations may not be obvious solely from analyses of traffic data; however, interviews with local planning or engineering personnel may result in the identification of such locations. These special cases may include access roads to major industrial facilities or office complexes, shopping centers, or public parking areas. Should locations such as this be identified, they should be entered on the Hot Spot Screening Summary Sheet.

5. Screening Locations Map

The final step in the hot spot screening process is to assign an identification number to each location listed on the Hot Spot Screening Summary Sheet, and then to plot the locations, with their respective identification numbers, on a base map. In preparing this map, separate symbols should be utilized to distinguish signalized intersections, nonsignalized intersections, and locations where uninterrupted flow prevails.

6. Nomographs and Worksheets

The following pages bring together most of the information that is needed to perform hot spot screening, assuming the user has become thoroughly familiar with both the general discussion of the concepts of hot spot analysis and the specific screening instructions presented above. These pages may be separated from this document and reproduced in order to provide a hot spot screening workbook. It is noted, again, that Volume III[3] of the Guidelines series provides a summary of the screening procedure and is designed specifically for easy use by an analyst who is familiar with the details of the screening procedure described here. Presented first in Figures 7 through 28 are nomographs for screening signalized intersections, arterial streets, expressways, and STOP-sign controlled intersections. Following these are Worksheets No. 1 through 5 to be used in performing the screening of a community and recording the results.

WORKSHEET NO. 1

Hot Spot Screening Summary Sheet

page ___ of ___

City/Town: ____________________ State: ____________________

Analysis By: ____________________ ____________________ Date: ________
(name) (title)

Approved By: ____________________ ____________________ Date: ________
(name) (title)

Location	Type	Hot Spot Indicated or Detailed Analysis Requirec	
		Yes	No

WORKSHEET NO. 2

Screening Worksheet - Signalized Intersections

page ___of ___

City/Town: ____________________ State: ____________________

Analysis By: ____________________ (name) ________________ (title) Date: ________

Approved By: ____________________ (name) ________________ (title) Date: ________

Part I Location: ____

Part II Congested Area? ____ Yes; ____ No

Part III Complex Intersection or Special Case? ____ Yes; ____ No; If yes, enter location on Initial Screening Summary Sheet and proceed to next intersection; if no, proceed with Part IV.

Part IV Analyze each approach separately on the form below.

Approach under analysis			Cross-street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Designation	b Adjusted ADT	c Configuration	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot spot indicated?
			Street: ________ Approach: ____				Street: ________ Approach: ____			

Part I Location: ____

Part II Congested Area? ____ Yes; ____ No

Part III Complex Intersection or Special Case? ____ Yes; ____ No; If yes, enter location on Initial Screening Summary Sheet and proceed to next intersection; if no, proceed with Part IV.

Part IV Analyze each approach separately on the form below.

Approach under analysis			Cross-street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Designation	b Adjusted ADT	c Configuration	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot spot indicated?
			Street: ________ Approach: ____				Street: ________ Approach: ____			

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WORKSHEET NO. 3

Screening Worksheet - Nonsignalized Intersections

page ___ of ___

City/Town: ____________________ State: ____________________

Analysis By: ____________________ (name) ____________________ (title) Date: __________

Approved By: ____________________ (name) ____________________ (title) Date: __________

Part I Location: ______________________________

Part II Analyze each cross street approach on the form below:

Through street data			Minor cross street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Adjusted ADT	b Configuration	c Hot Spot indicated?	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot Spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot Spot indicated?

Part I Location: ______________________________

Part II Analyze each cross street approach on the form below:

Through street data			Minor cross street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Adjusted ADT	b Configuration	c Hot Spot indicated?	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot Spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot Spot indicated?

Part I Location: ______________________________

Part II Analyze each cross street approach on the form below:

Through street data			Minor cross street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Adjusted ADT	b Configuration	c Hot Spot indicated?	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot Spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot Spot indicated?

Part I Location: ______________________________

Part II Analyze each cross street approach on the form below:

Through street data			Minor cross street data							
			Street: ________ Approach: ____				Street: ________ Approach: ____			
a Adjusted ADT	b Configuration	c Hot Spot indicated?	d Adjusted ADT	e Configuration	f Figure/ curve used	g Hot Spot indicated?	h Adjusted ADT	i Configuration	j Figure/ curve used	k Hot Spot indicated?

WORKSHEET NO. 4

Screening Worksheet - Uninterrupted Flow

City/Town: ______________________ **State:** ____________ page ___ of ___

Analysis By: ______________________ (name) ______________________ (title) **Date:** ________

Approved By: ______________________ (name) ______________________ (title) **Date:** ________

a Facility	b Location	c Adjusted ADT	d Configuration	e Est. lane capacity	f Hot Spot indicated?

D. METHODS OF ESTIMATING ROADWAY CAPACITY

This section provides a methodology for calculating roadway or lane capacities, based on the Highway Capacity Manual,[9] for use in the hot spot screening procedures.

The methodology developed here is conservative in that it tends to underestimate capacity.

The Highway Capacity Manual (1965)[9] gives the following maximum uninterrupted flow capacities under ideal conditions for various types of roadways:

Highway type	Capacity (vph)
Multilane	2,000 per lane
Two-lane, two-way*	2,000 total (both directions)
Three-lane, two-way	4,000 total (both directions)

The capacity, C, of a multilane roadway is computed using the following equation:

$$C = 2000\ M\ Wf\ T; \qquad (4)$$

the capacity for one direction of a two-lane roadway is computed using the equation:

$$C = 1000\ Wf\ T \qquad (5)$$

where M = number of lanes moving in one direction
Wf = adjustment factor for lane width from Table 6
T = truck factor from Table 7.

---

*This applies primarily to rural locations where speed ranges are quite high; for most urban applications, capacity can be assumed to be about 2000 vehicles per hour for each direction.

Table 6. COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUMES OF DIVIDED FREEWAYS AND EXPRESSWAYS AND TWO-LANE HIGHWAYS WITH UNINTERRUPTED FLOW

Distance from traffic lane edge to obstruction	Adjustment factor, Wf, for lane width and lateral clearance							
	Obstruction of one side of one-direction roadway				Obstructions on both sides of one-direction roadway			
	12-ft lanes	11-ft lanes	10-ft lanes	9-ft lanes	12-ft lanes	11-ft lanes	10-ft lanes	9-ft lanes
Four-lane divided freeway, one direction of travel								
6	1.00	0.97	0.91	0.81	1.00	0.97	0.91	0.81
4	0.99	0.96	0.90	0.80	0.98	0.95	0.89	0.79
2	0.97	0.94	0.88	0.79	0.94	0.91	0.86	0.76
0	0.90	0.87	0.82	0.73	0.81	0.79	0.74	0.66
Six- and eight-lane divided freeways, one direction of travel								
6	1.00	0.96	0.89	0.78	1.00	0.96	0.89	0.78
4	0.99	0.95	0.88	0.77	0.98	0.94	0.87	0.77
2	0.97	0.93	0.87	0.76	0.96	0.92	0.85	0.75
0	0.94	0.91	0.85	0.74	0.91	0.87	0.81	0.70
Two-lane highway, one direction of travel								
6	1.00	0.88	0.81	0.76	1.00	0.88	0.81	0.76
4	0.97	0.85	0.79	0.74	0.94	0.83	0.76	0.71
2	0.93	0.81	0.75	0.70	0.85	0.75	0.69	0.65
0	0.88	0.77	0.71	0.66	0.76	0.67	0.62	0.58

Table 7. AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR TRUCKS ON FREEWAYS AND EXPRESSWAYS, AND 2-LANE HIGHWAYS OVER EXTENDED SECTION LENGTHS

Pt, percentage of trucks, %	Factor, T, for all levels of service		
	Level terrain	Rolling terrain	Mountainous terrain
	Freeways and expressways		
1	0.99	0.97	0.93
2	0.98	0.94	0.88
3	0.97	0.92	0.83
4	0.96	0.89	0.78
5	0.95	0.87	0.74
6	0.94	0.85	0.70
7	0.93	0.83	0.67
8	0.93	0.81	0.64
9	0.92	0.79	0.61
10	0.91	0.77	0.59
11	0.89	0.74	0.54
14	0.88	0.70	0.51
16	0.86	0.68	0.47
18	0.85	0.65	0.44
20	0.83	0.63	0.42
	Two-lane highways		
1	0.99	0.96	0.90
2	0.98	0.93	0.82
3	0.97	0.89	0.75
4	0.96	0.86	0.69
5	0.95	0.83	0.65
6	0.94	0.81	0.60
7	0.93	0.78	0.57
8	0.93	0.76	0.53
9	0.92	0.74	0.50
10	0.91	0.71	0.48
12	0.89	0.68	0.43
14	0.88	0.64	0.39
16	0.86	0.61	0.36
18	0.85	0.58	0.34
20	0.83	0.56	0.31

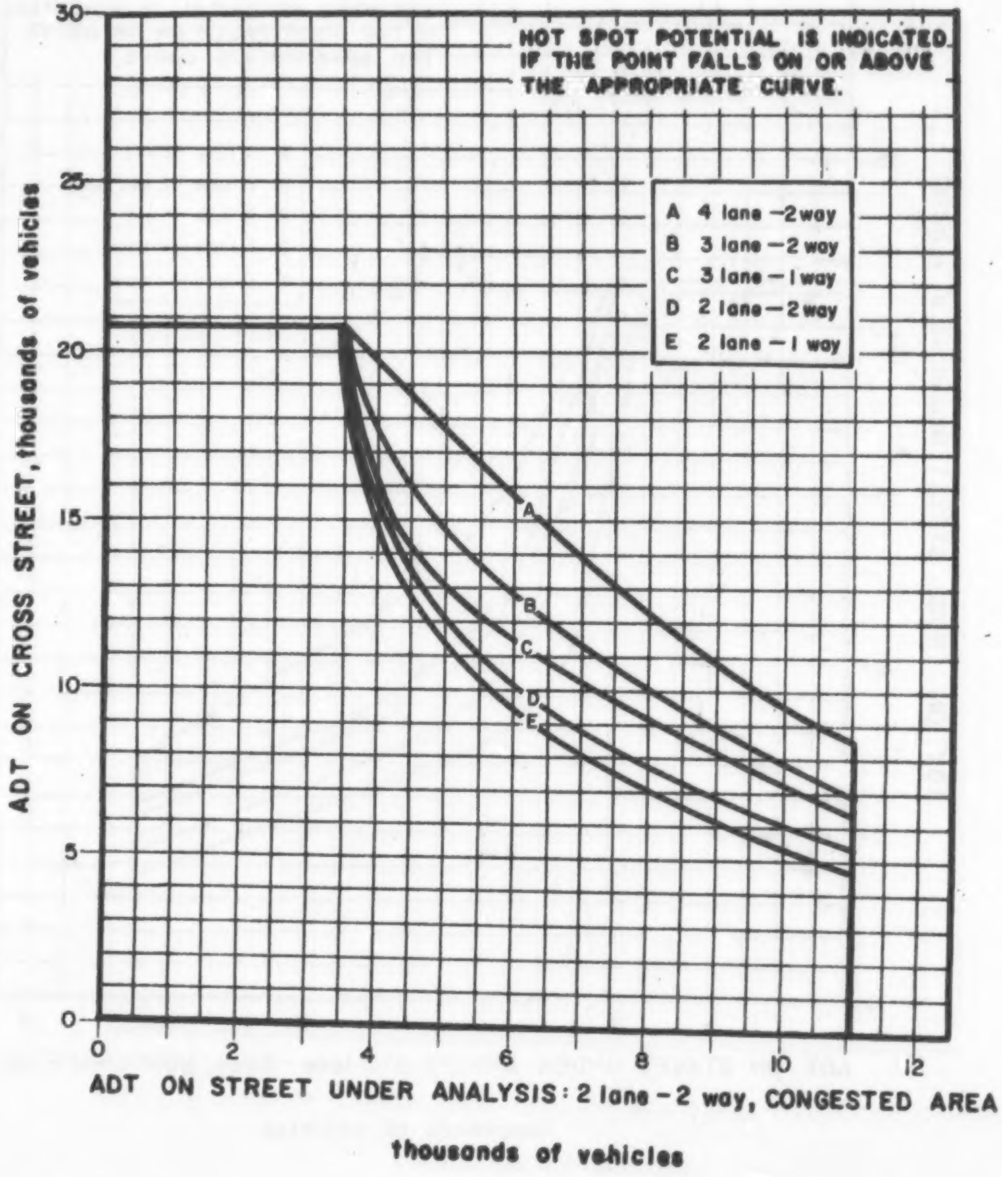


Figure 7. Analysis at signalized intersections of a 2-lane, 2-way street and various cross street configurations in a congested area

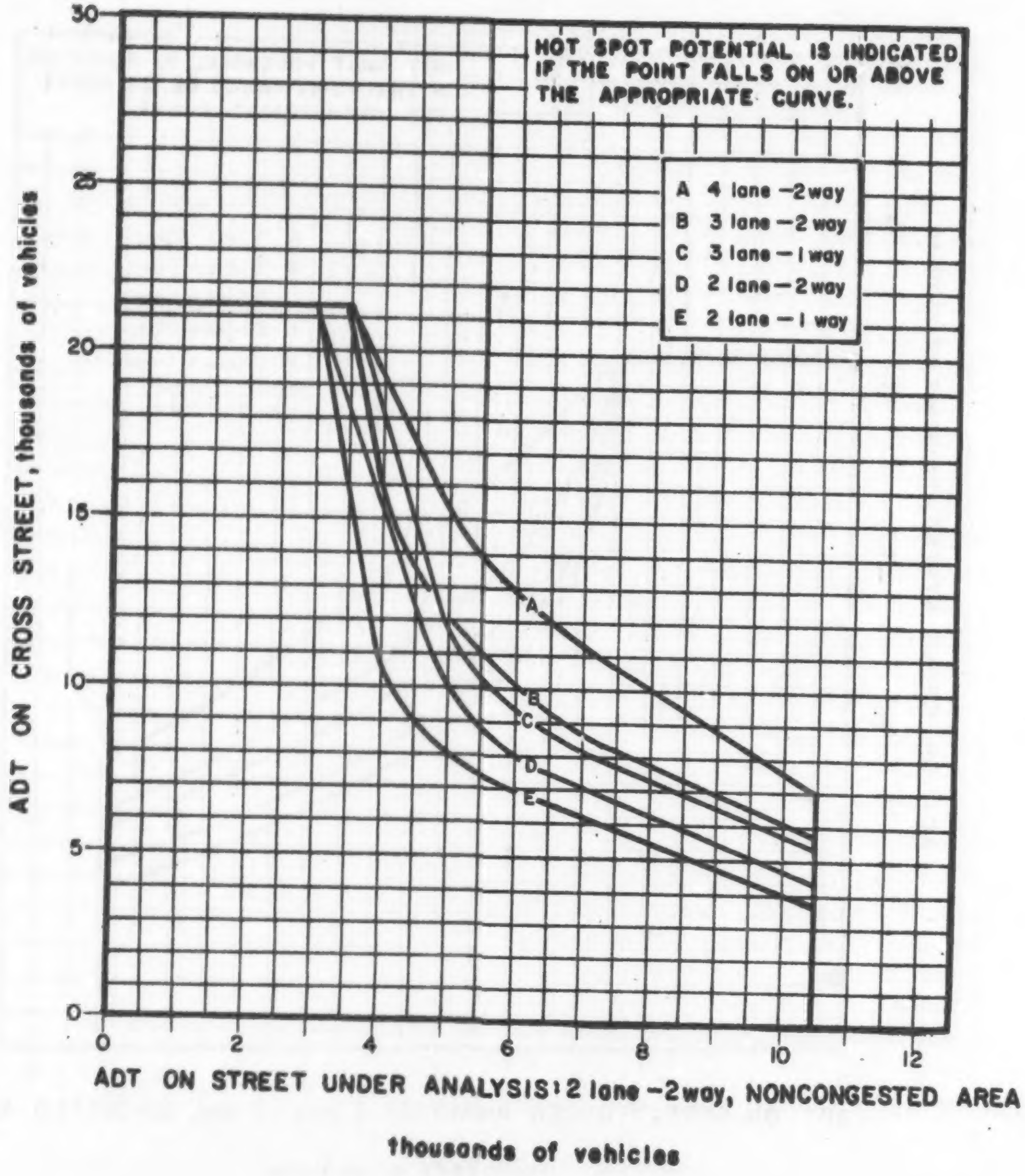


Figure 8. Analysis at signalized intersections of a 2-lane, 2-way street and various cross street configurations in a noncongested area

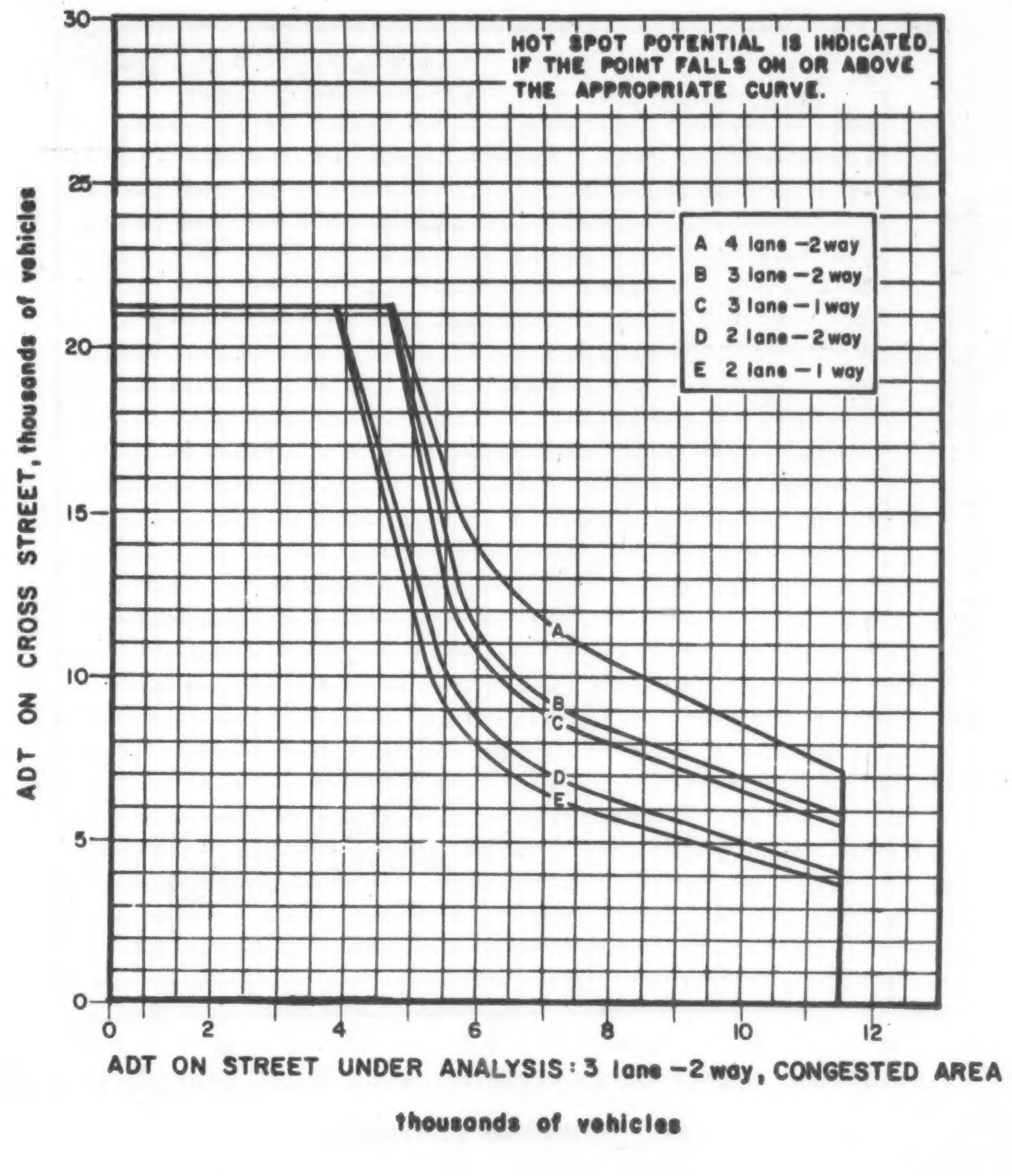


Figure 9. Analysis at signalized intersections of a 3-lane, 2-way street and various cross street configurations in a congested area

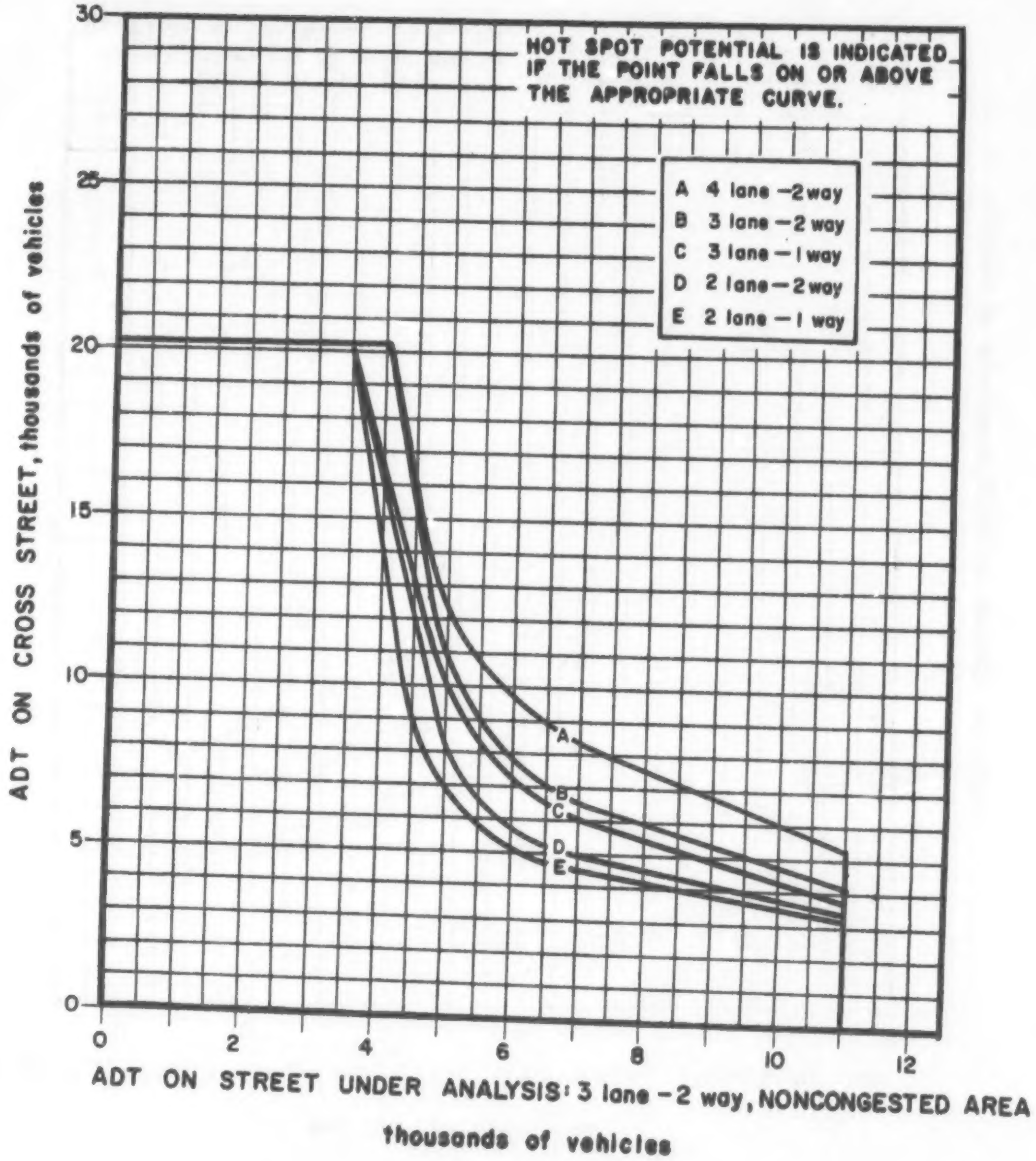


Figure 10. Analysis at signalized intersections of a 3-lane, 2-way street and various cross street configurations in a noncongested area

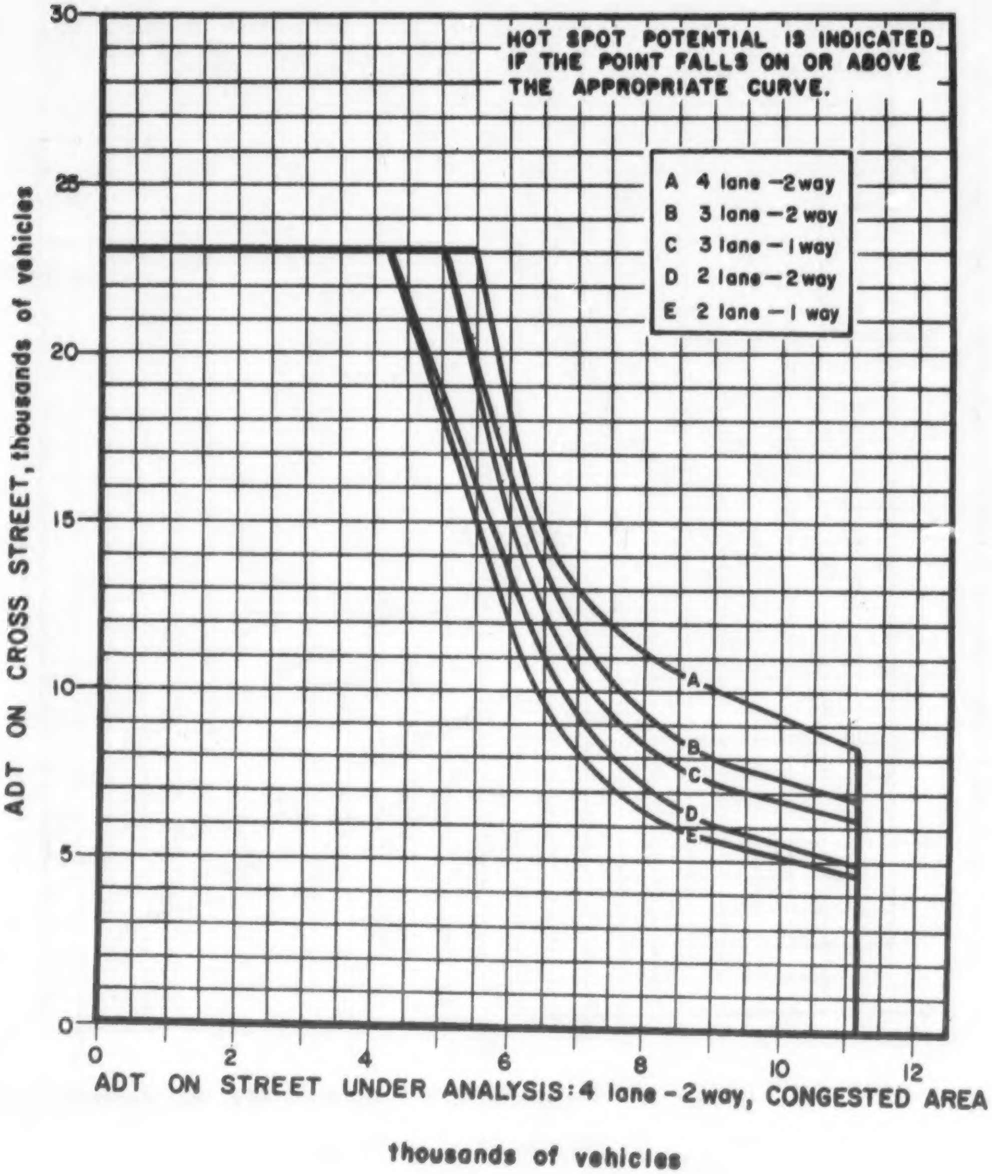


Figure 11. Analysis at signalized intersections of a 4-lane, 2-way street and various cross street configurations in a congested area

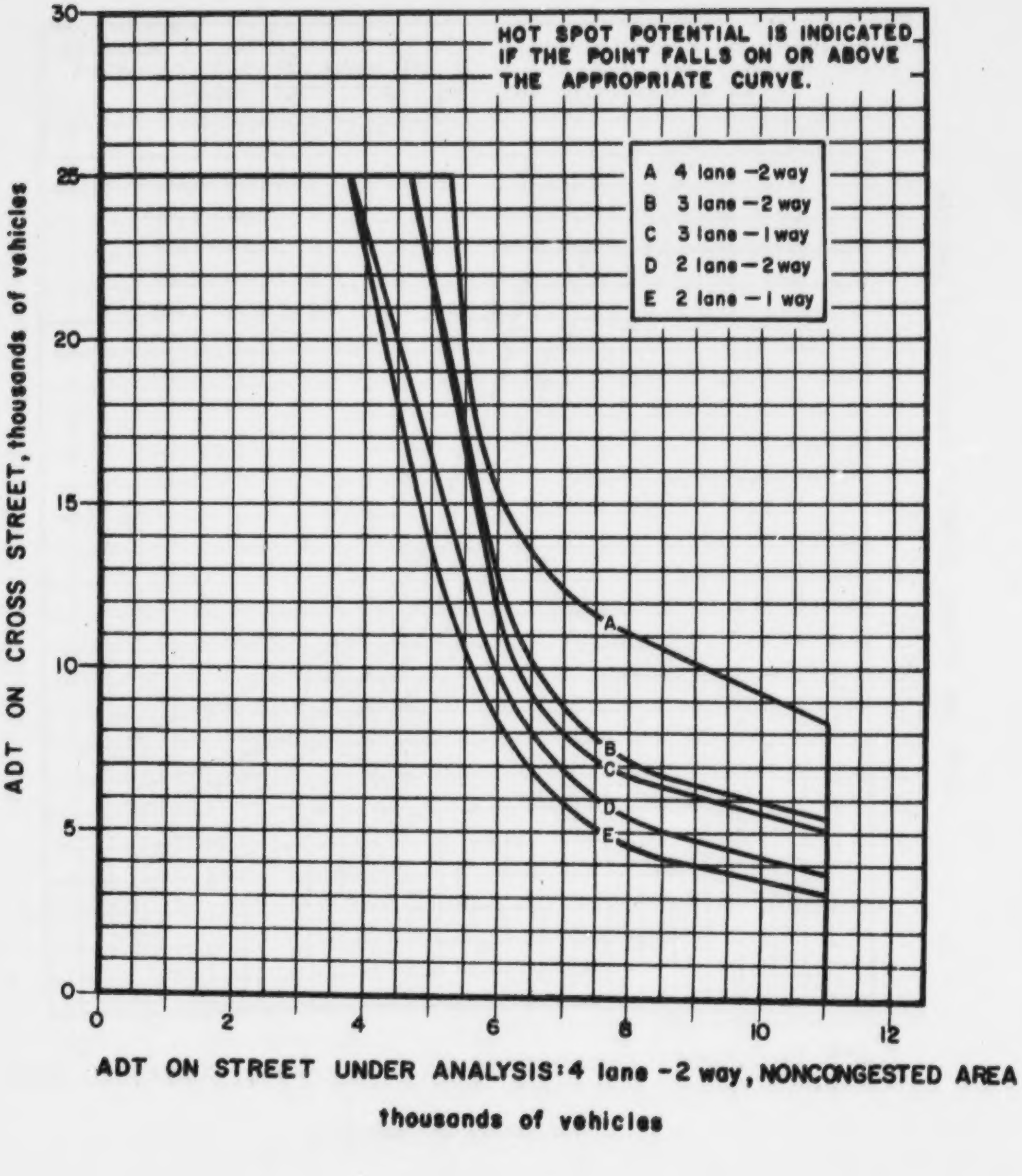


Figure 12. Analysis at signalized intersections of a 4-lane, 2-way street and various cross street configurations in a noncongested area

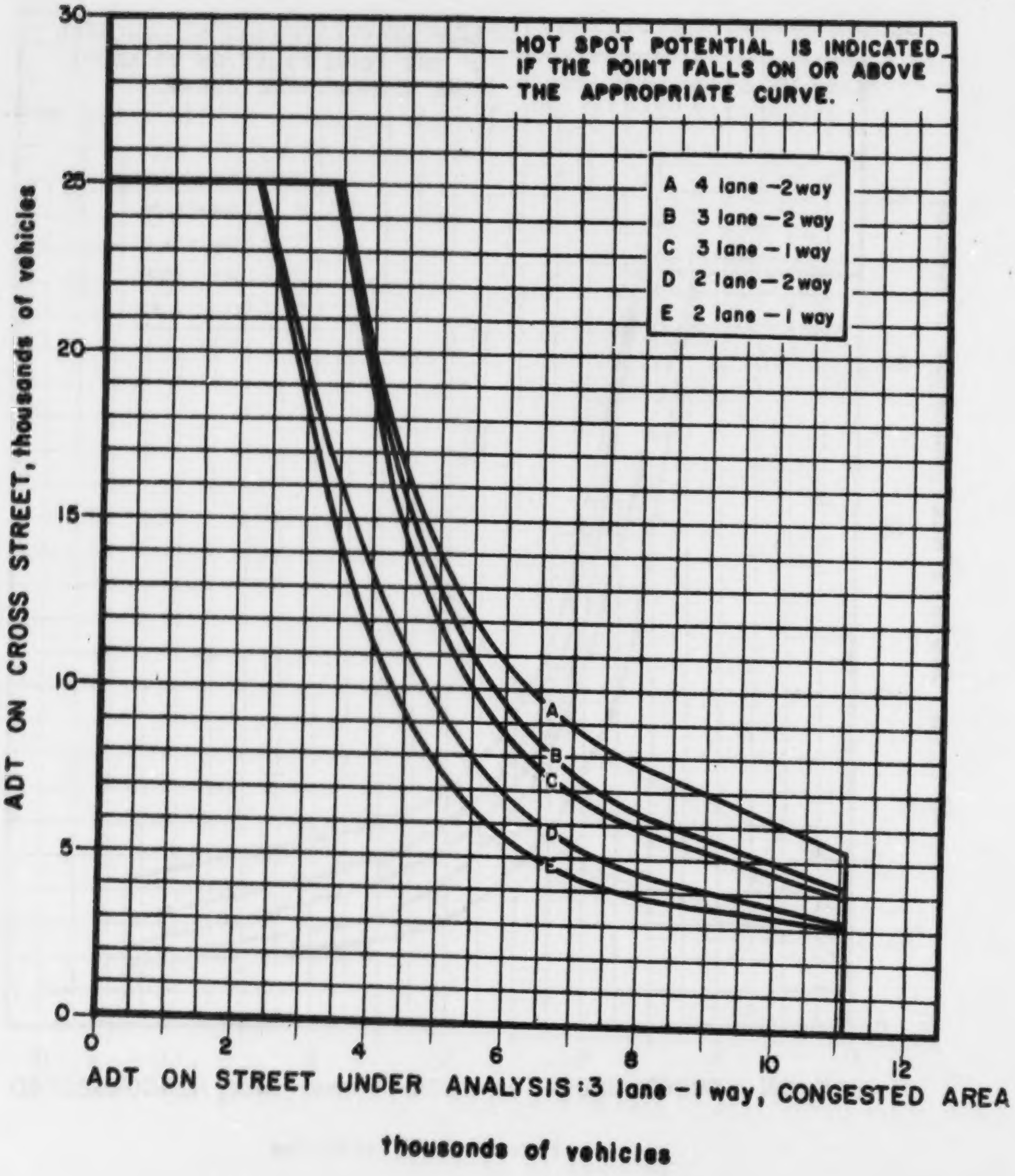


Figure 13. Analysis at signalized intersections of a 3-lane, 1-way street and various cross street configurations

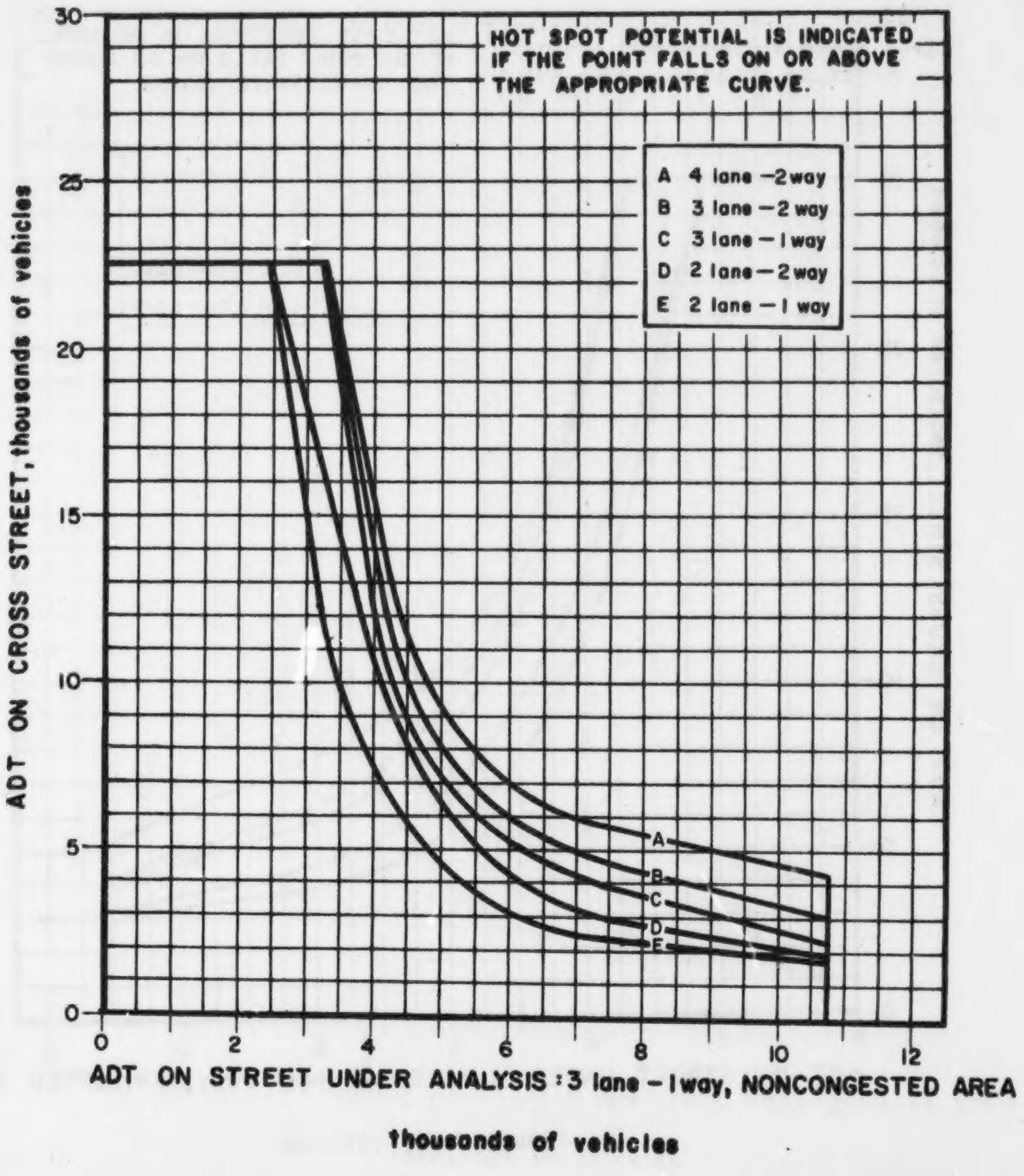


Figure 14. Analysis at signalized intersections of a 3-lane, 1-way street and various cross street configurations for noncongested areas

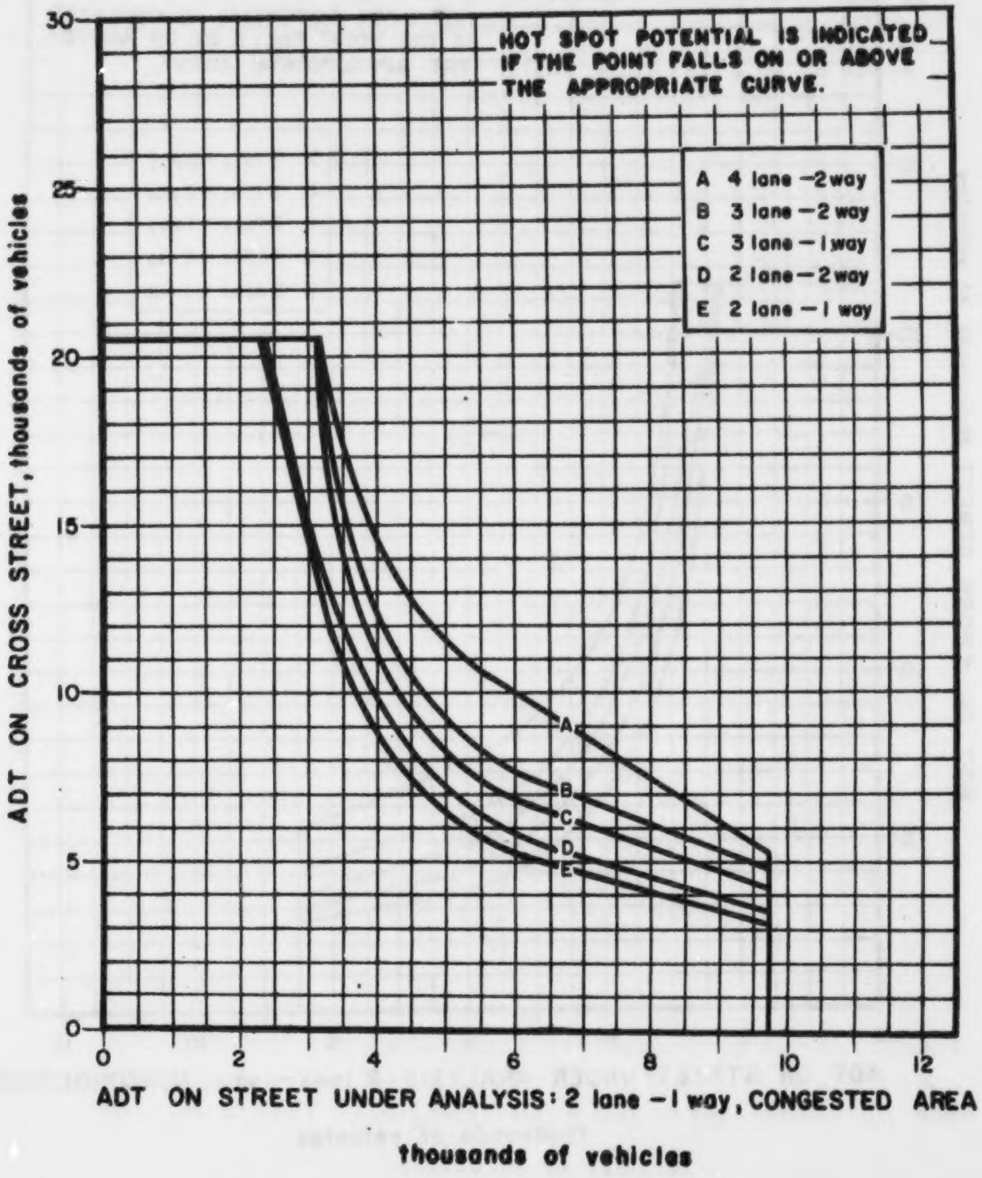


Figure 15. Analysis of signalized intersections of a 2-lane, 1-way street and various cross street configurations

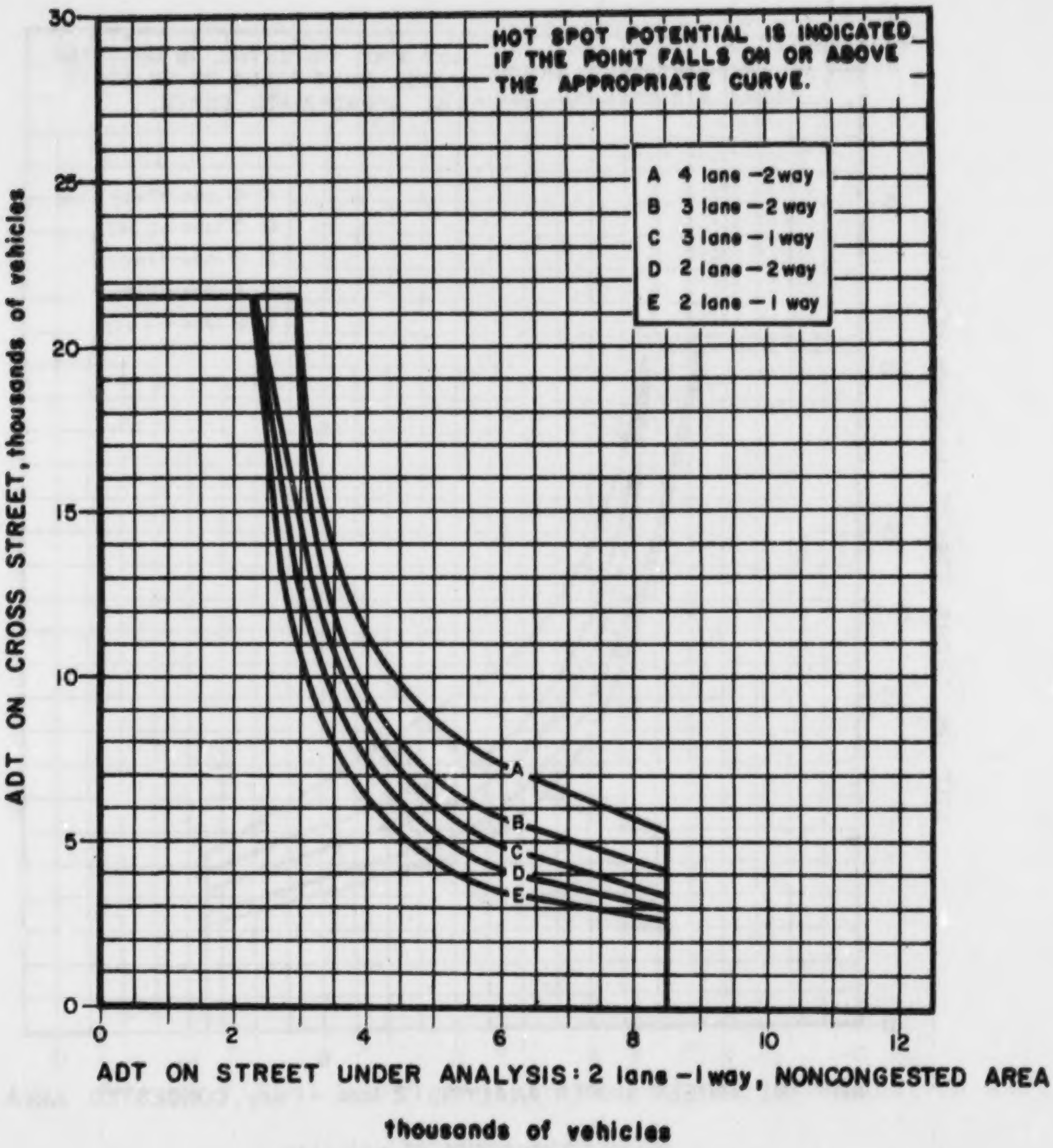


Figure 16. Analysis at signalized intersections for a 2-lane, 1-way street and various cross street configurations in noncongested areas

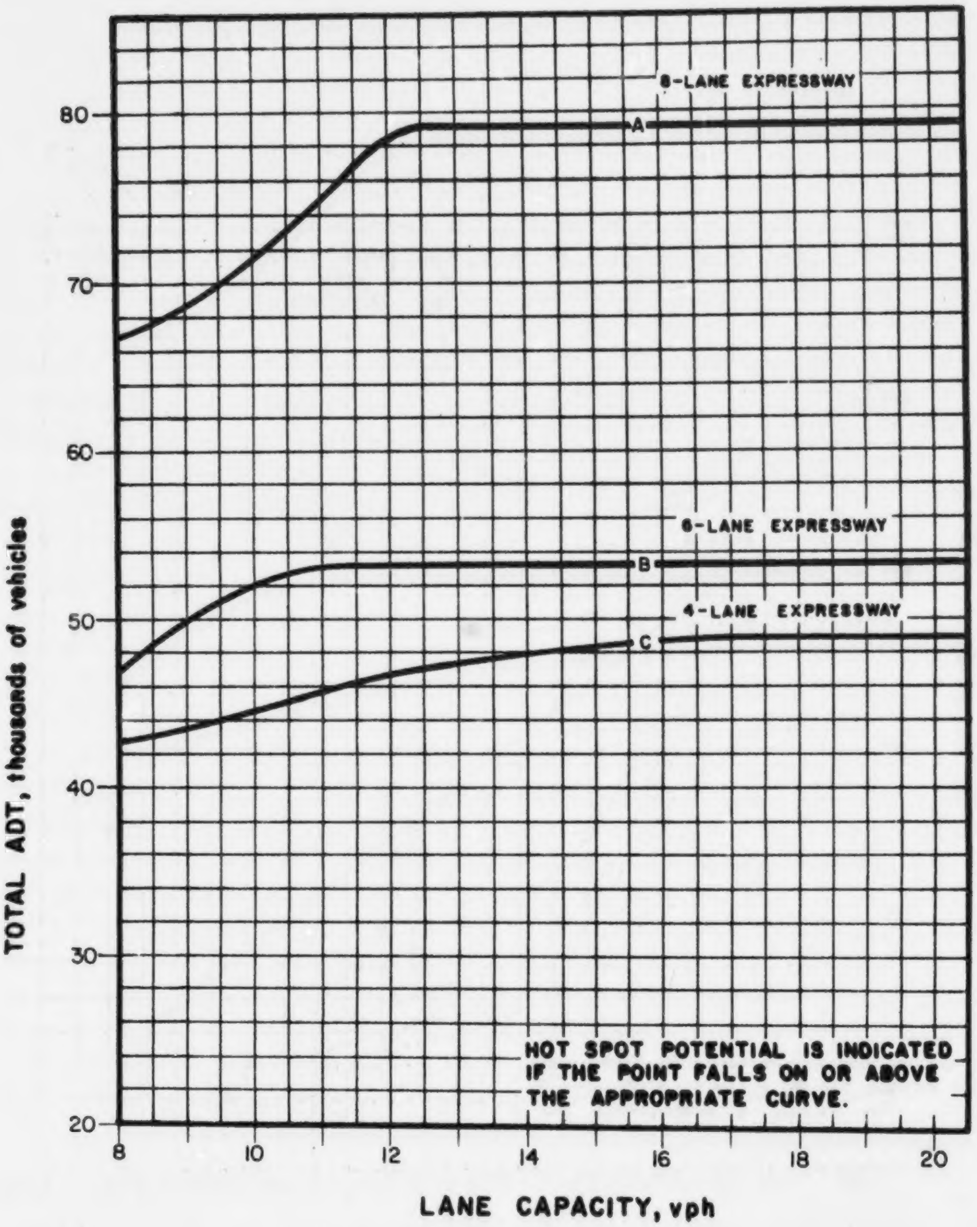


Figure 17. Analysis for uninterrupted flow conditions of controlled access facilities (expressways) for various lane configurations

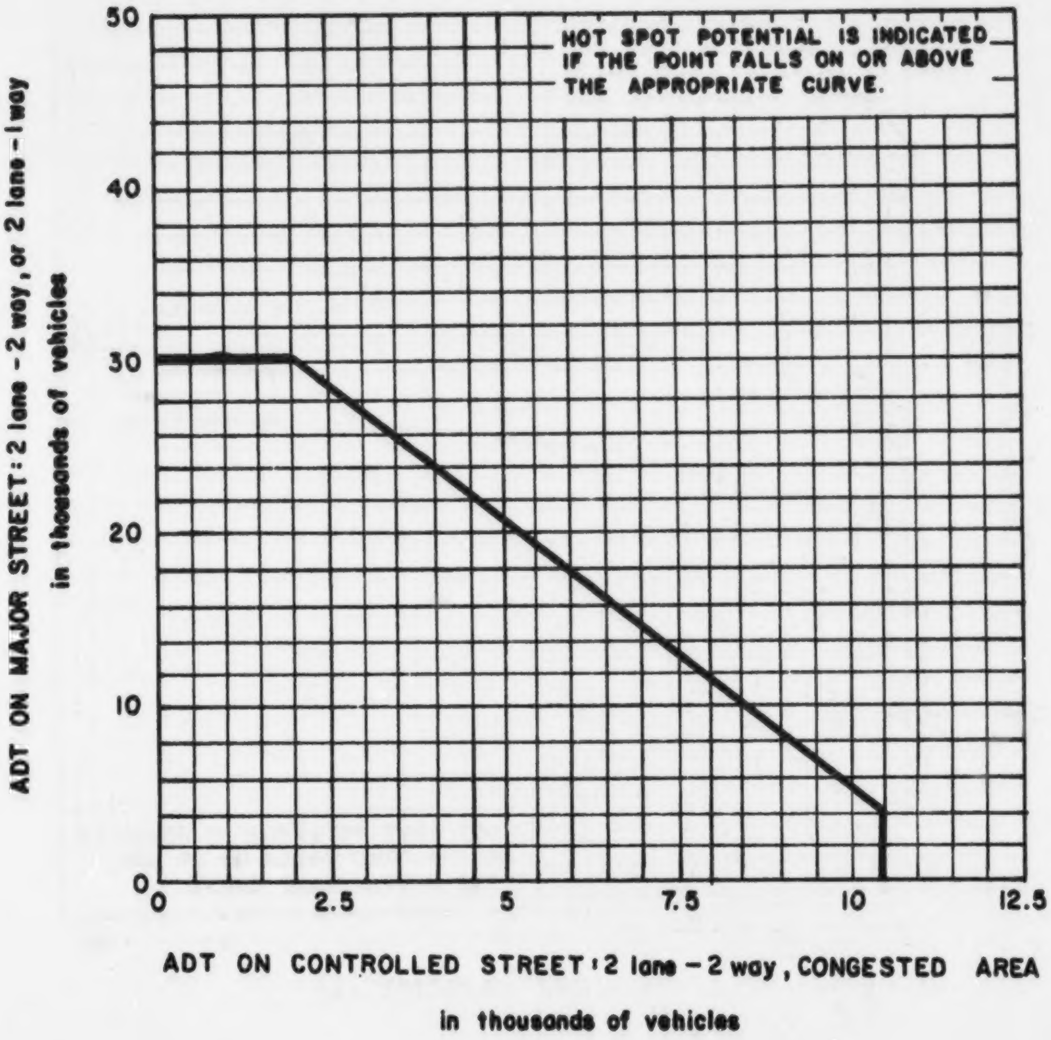


Figure 19. Analysis at nonsignalized intersections of a 2-lane, 2-way controlled street intersecting a 2-lane, 2-way or 2-lane, 1-way major street in a congested area

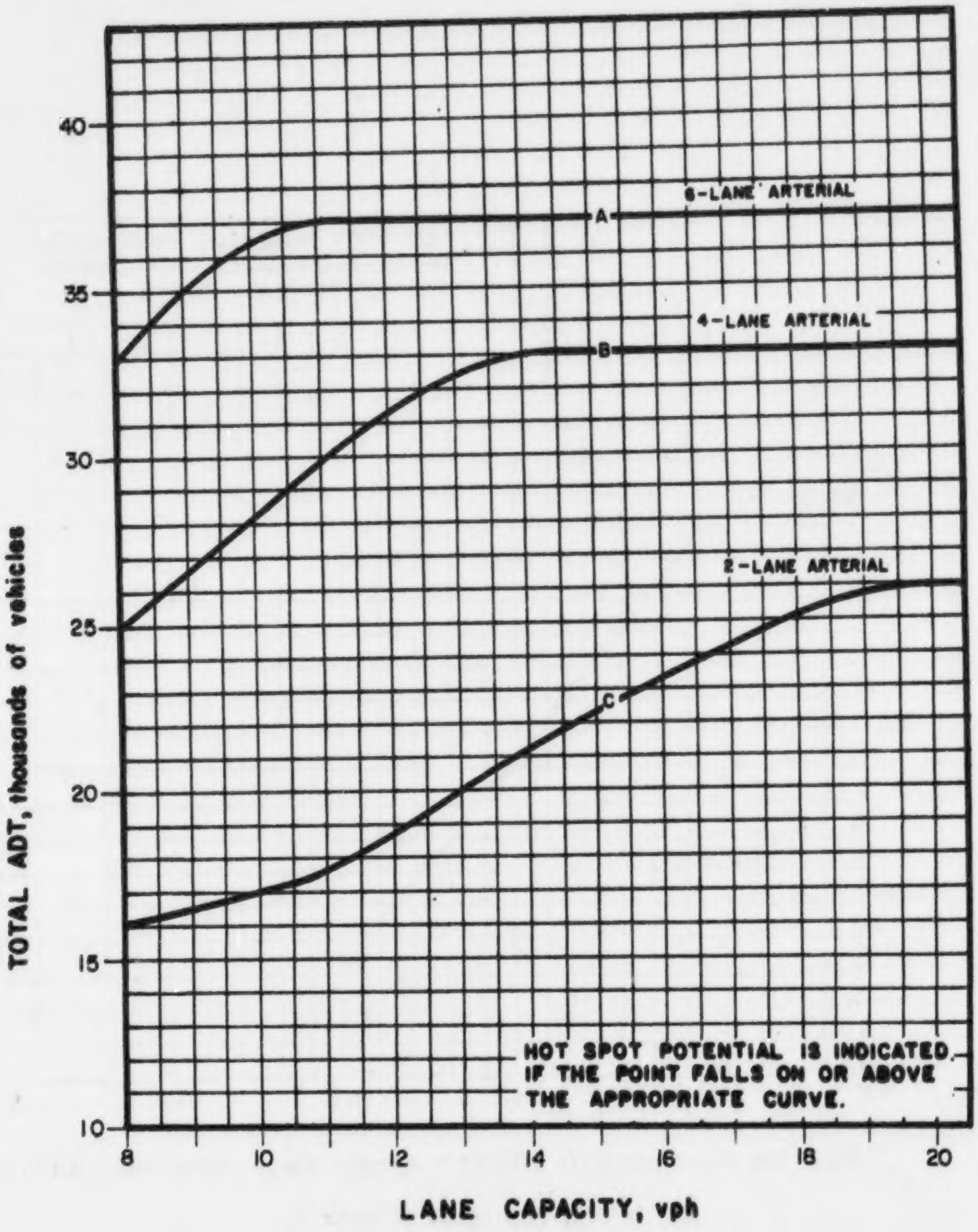


Figure 18. Analysis for uninterrupted flow conditions of uncontrolled access facilities (arterials) for various lane configurations

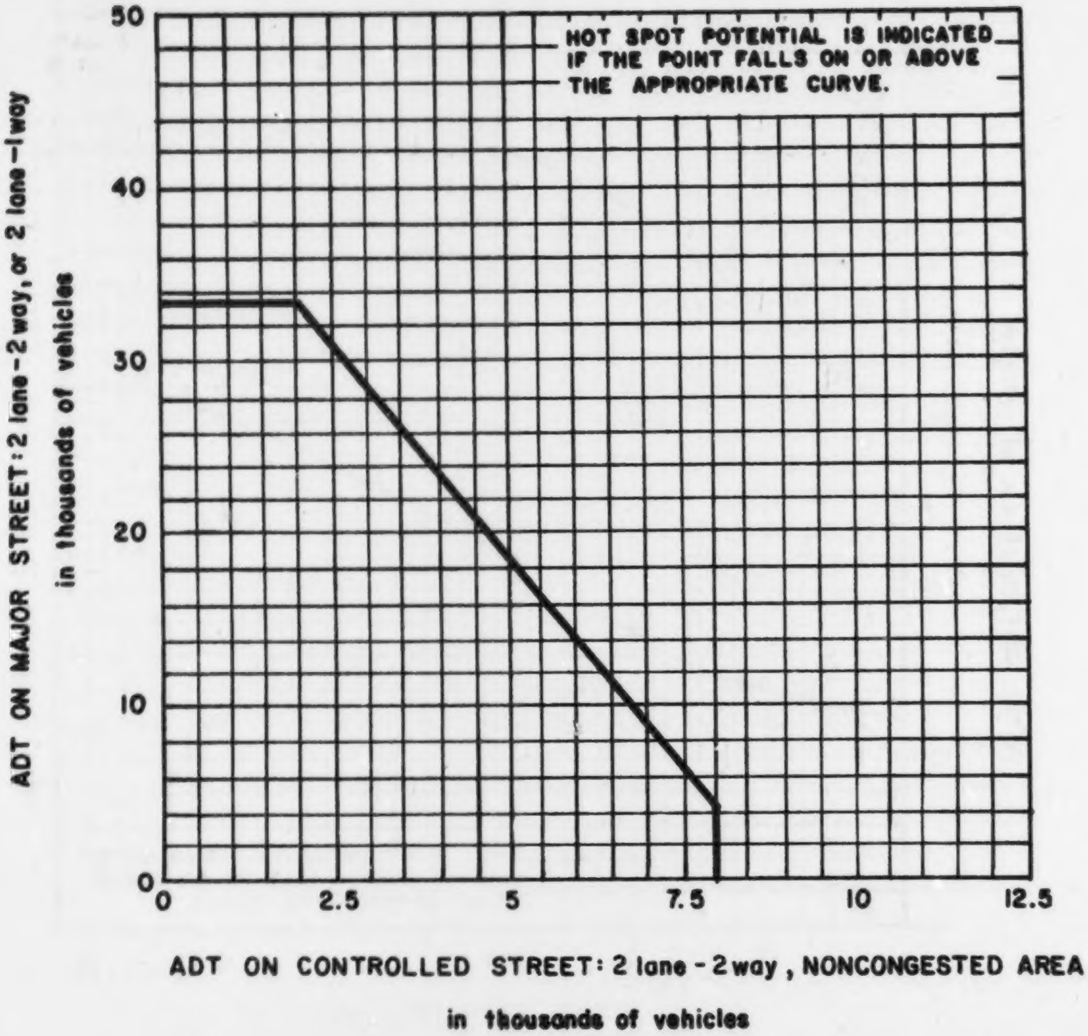


Figure 20. Analysis at nonsignalized intersections of a 2-lane, 2-way controlled street intersecting a 2-lane, 2-way or 2-lane, 1-way major street in a noncongested area

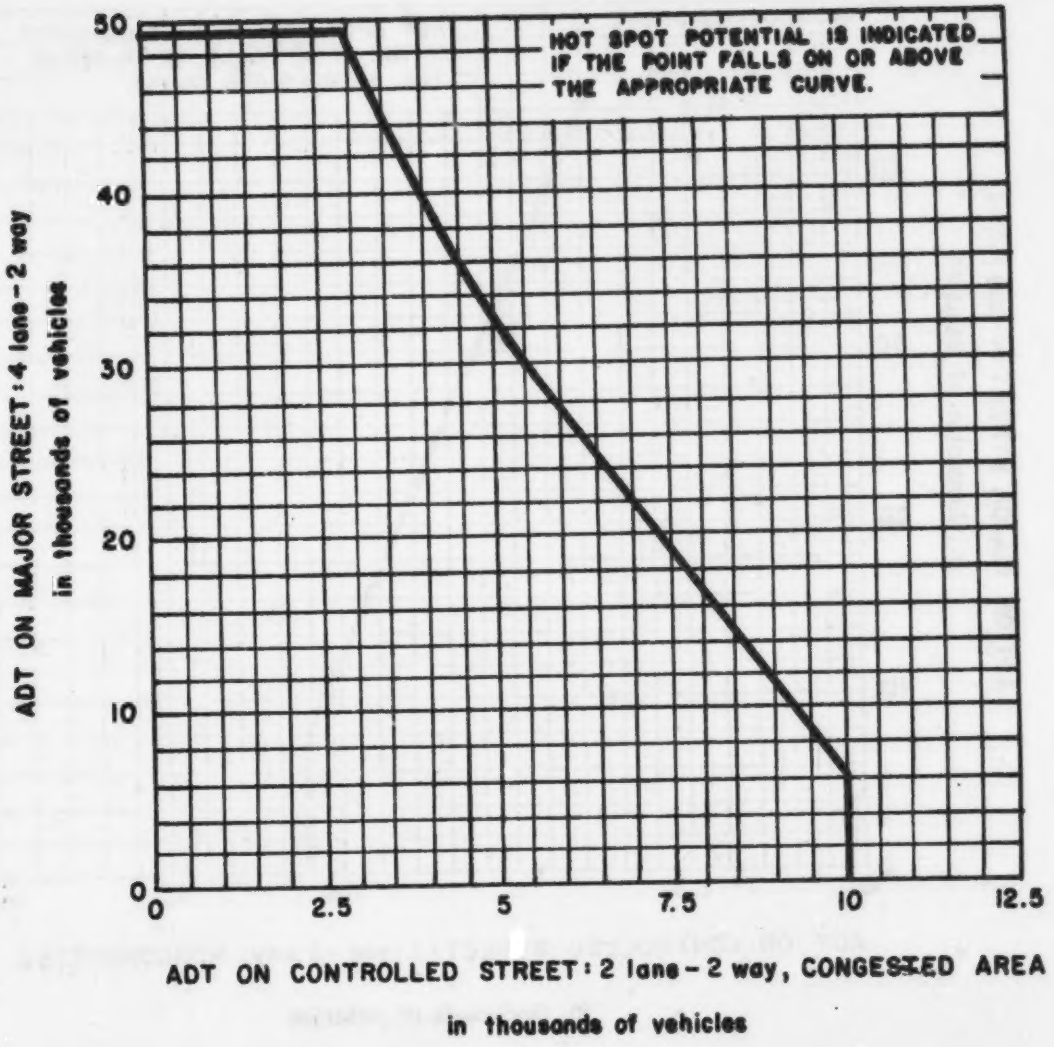


Figure 21. Analysis at nonsignalized intersections of a 2-lane, 2-way controlled street intersecting a 4-lane, 2-way major street in a congested area

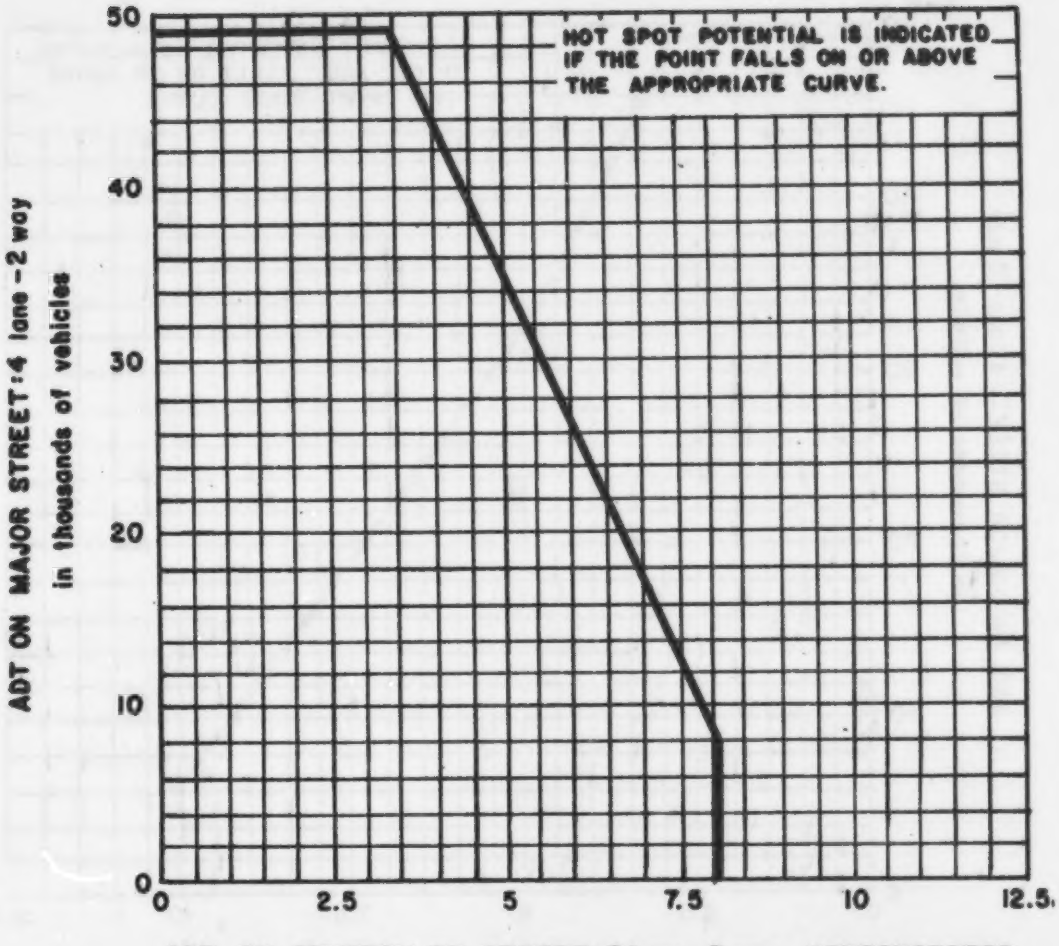


Figure 22. Analysis at nonsignalized intersections of a 2-lane, 2-way controlled street intersecting a 4-lane, 2-way major street in a noncongested area

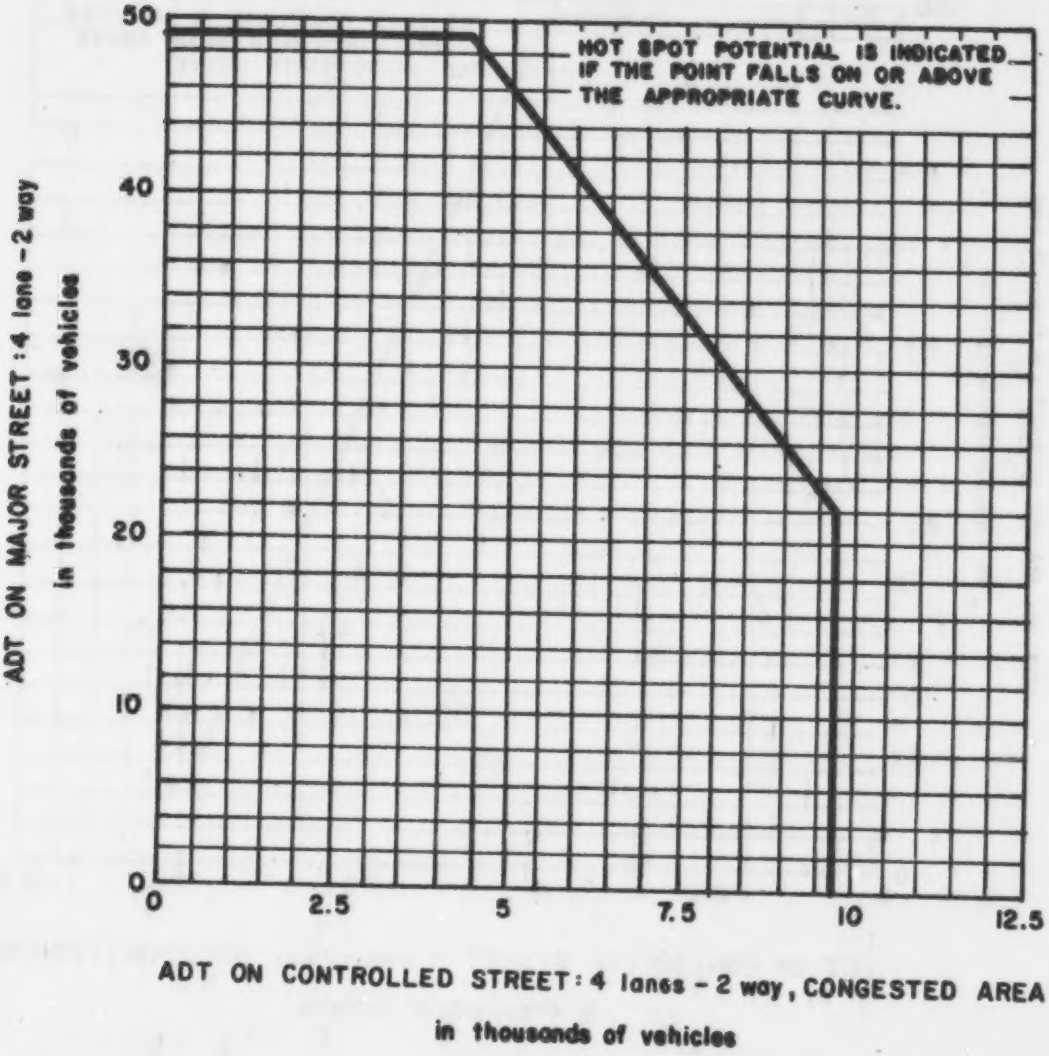


Figure 23. Analysis at nonsignalized intersections of a 4-lane, 2-way controlled street intersecting a 4-lane, 2-way major street in a congested area

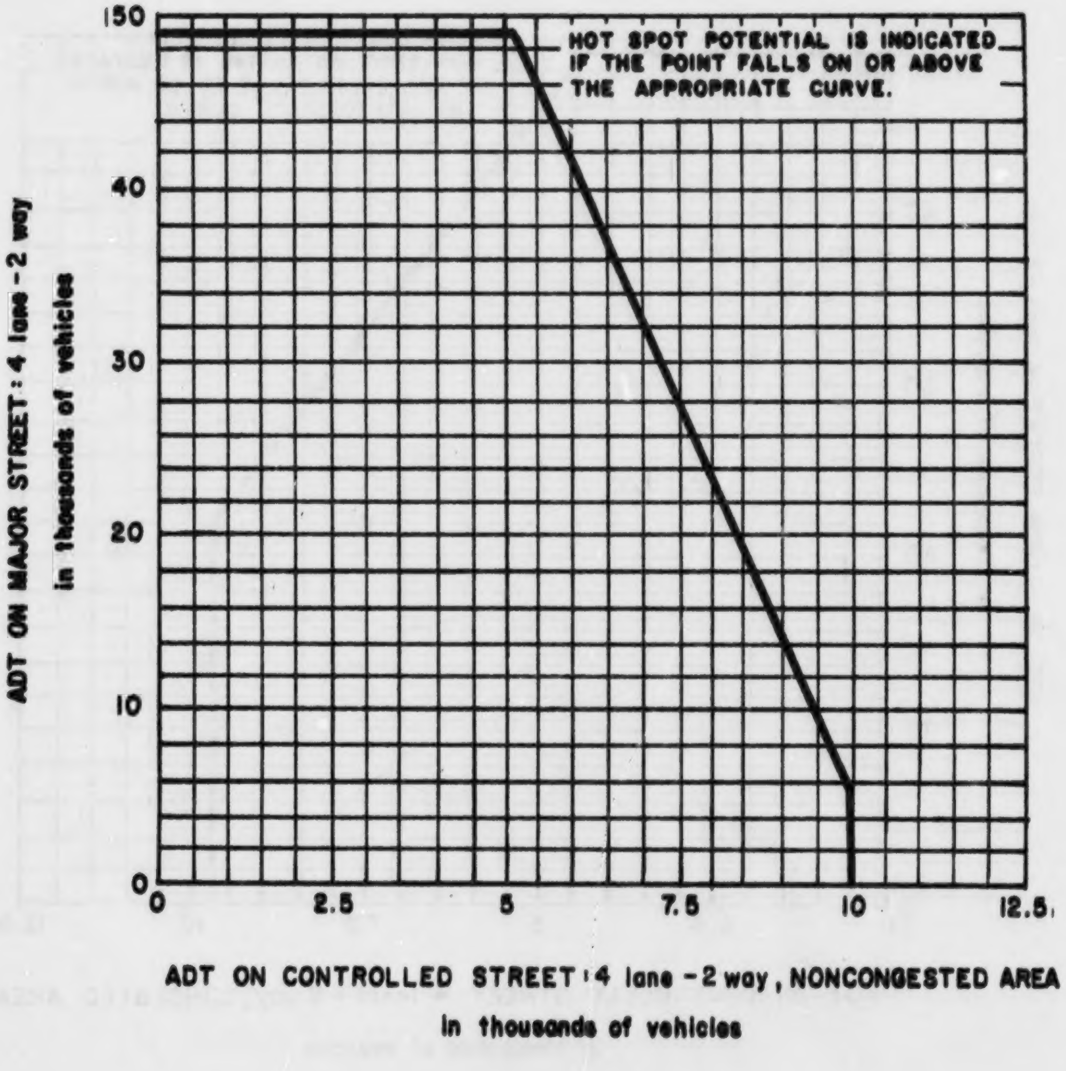


Figure 24. Analysis at nonsignalized intersections of a 4-lane, 2-way controlled street intersecting a 4-lane, 2-way major street in a noncongested area

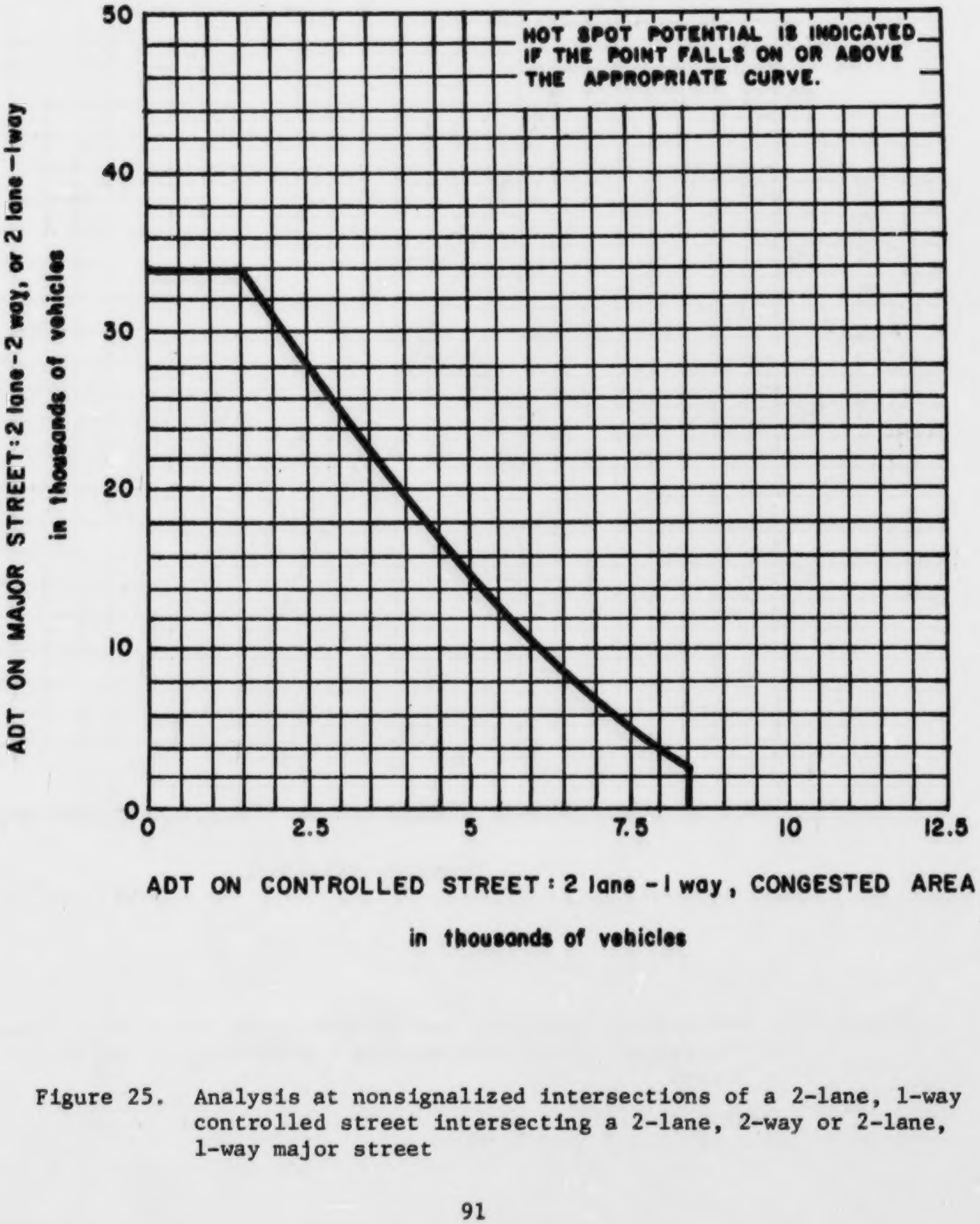


Figure 25. Analysis at nonsignalized intersections of a 2-lane, 1-way controlled street intersecting a 2-lane, 2-way or 2-lane, 1-way major street

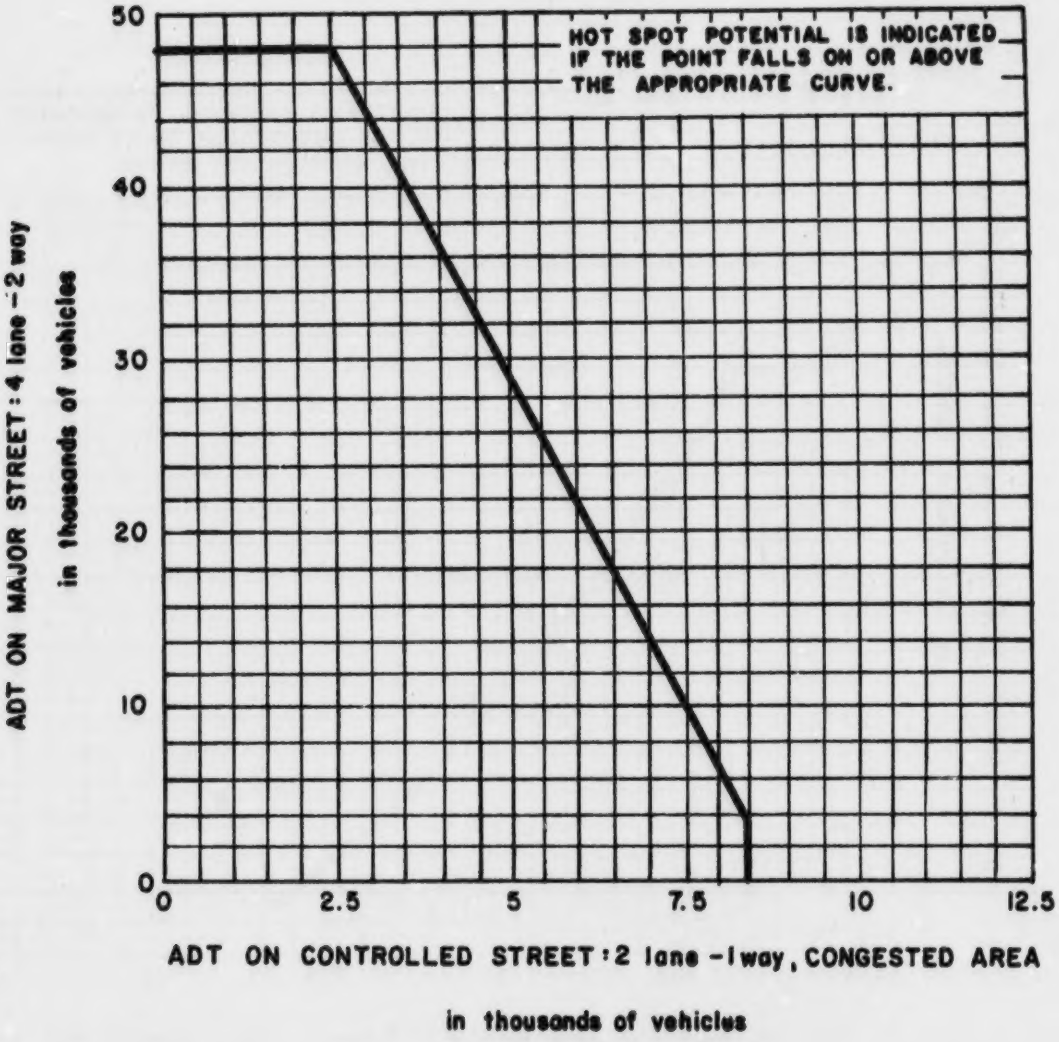


Figure 27. Analysis at nonsignalized intersections of a 2-lane, 1-way controlled street intersecting a 4-lane, 2-way major street

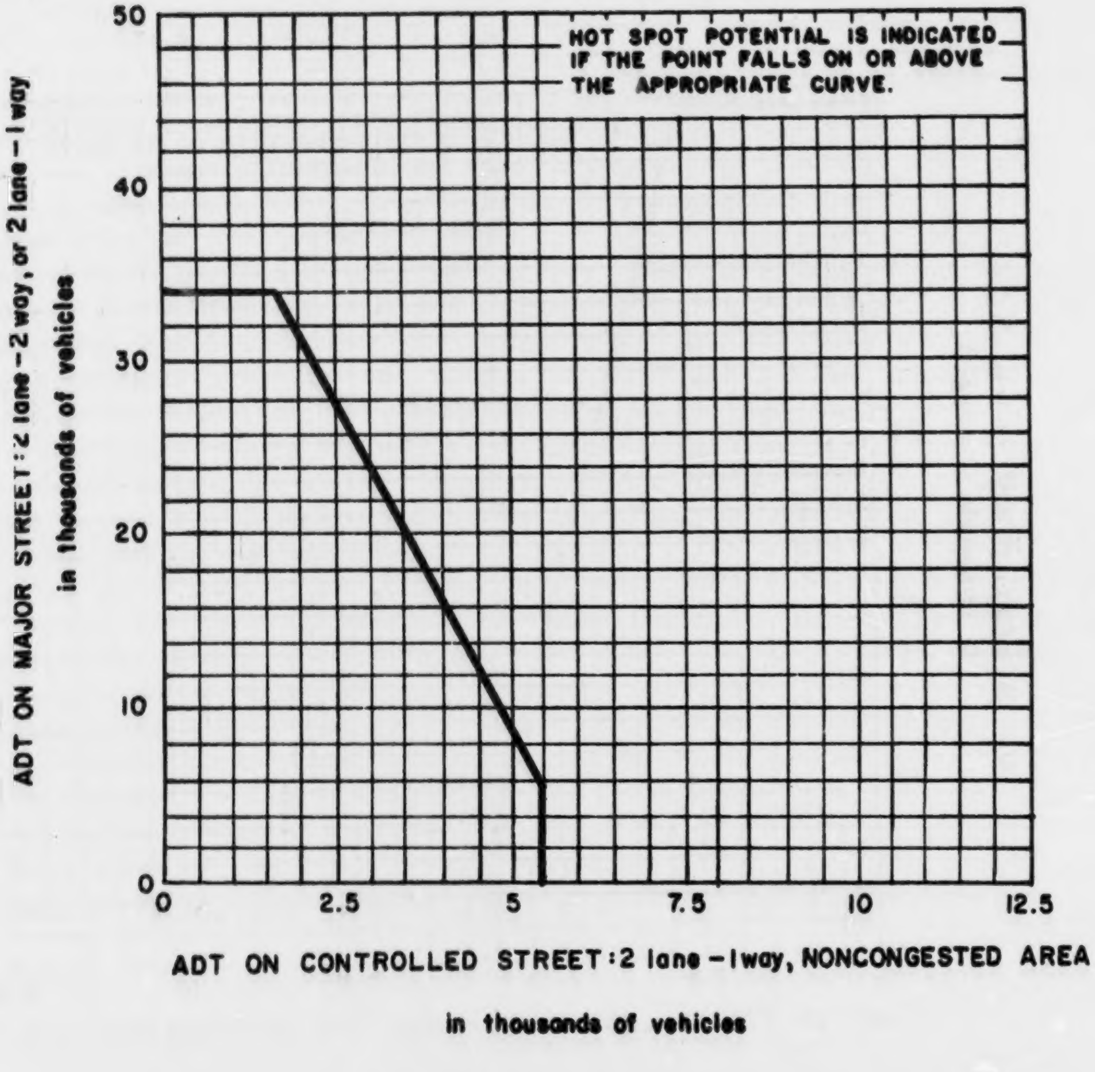


Figure 26. Analysis at nonsignalized intersections of a 2-lane, 1-way controlled street intersecting a 2-lane, 2-way or 2-lane 1-way major street in a noncongested area

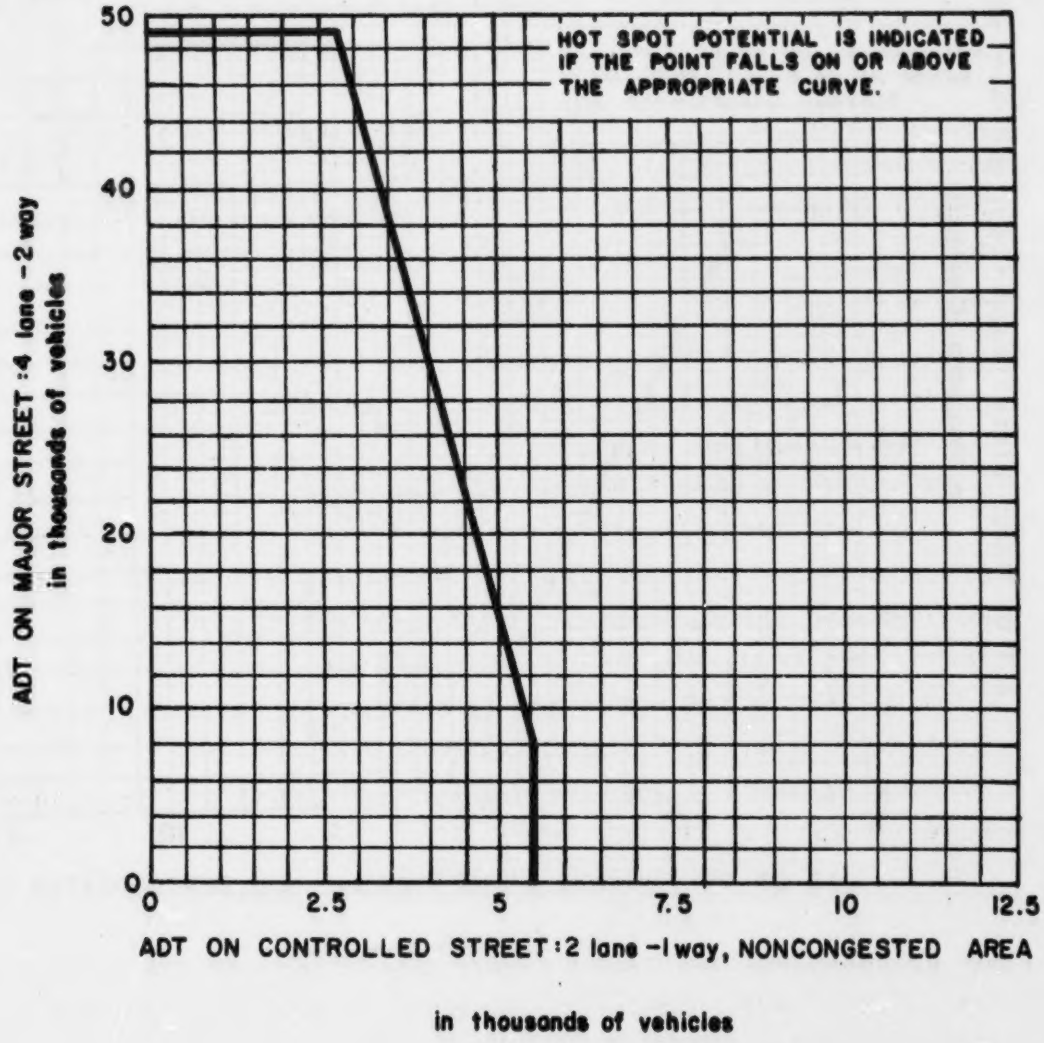


Figure 28. Analysis at nonsignalized intersections of a 2-lane, 1-way controlled street intersecting a 4-lane, 2-way major street in a noncongested area

E. EXAMPLE

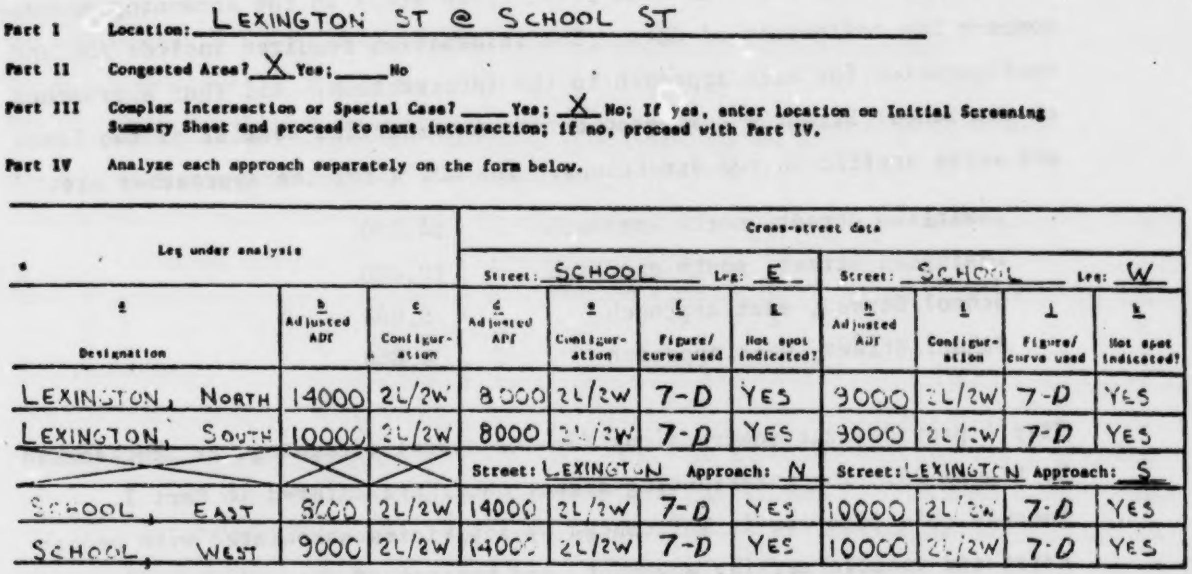
An example is provided in Figure 29 of the screening of a signalized intersection, School Street at Lexington Street. The traffic data required to perform the screening were presented previously in Section II.F. (See Figure 5 in Section II.F for details of the intersection layout.)

The detailed instructions for screening signalized intersections were presented in Section III.C.1. The first three steps in the screening process concern the collection of data. The information required include ADT and configuration for each approach to the intersection. All four approaches at the School Street - Lexington Street intersection consist of two lanes and serve traffic in two directions. The ADT's for the approaches are:

Lexington Street, north approach	14,000
Lexington Street, south approach	10,000
School Street, east approach	8,000
School Street, west approach	9,000

Step 4 provides the instructions for the actual screening, as represented by Figure 29. The intersecting street names are entered in Part I. Because this location is influenced by activities associated with pedestrian and vehicle parking movement, and because of the narrow roadway width and influence from nearby intersections, it has been determined that the intersection should be classified as a congested area. This fact is recorded in Part II. The intersection is neither complex nor a special case; this is recorded in Part III.

The procedure set down in Part IV analyzes the hot spot potential of the intersection. *All intersection approaches are analyzed.* Only one approach, Lexington Street north, is described here, however. The information is recorded as shown in Figure 29. The approach under analysis, its ADT, and its configuration are entered in Columns a, b, and c, respectively. The ADTs and the configuration of the cross street (School Street) approaches



Part I Location: LEXINGTON ST @ SCHOOL ST

Part II Congested Area? X Yes; ____ No

Part III Complex Intersection or Special Case? ____ Yes; X No; If yes, enter location on Initial Screening Summary Sheet and proceed to next intersection; if no, proceed with Part IV.

Part IV Analyze each approach separately on the form below.

Leg under analysis			Cross-street data							
			Street: SCHOOL Leg: E				Street: SCHOOL Leg: W			
a Designation	b Adjusted ADT	c Configuration	d Adjusted ADT	e Configuration	f Figure/curve used	g Hot spot indicated?	h Adjusted ADT	i Configuration	j Figure/curve used	k Hot spot indicated?
LEXINGTON, NORTH	14000	2L/2W	8000	2L/2W	7-D	YES	9000	2L/2W	7-D	YES
LEXINGTON, SOUTH	10000	2L/2W	8000	2L/2W	7-D	YES	9000	2L/2W	7-D	YES
			Street: LEXINGTON Approach: N				Street: LEXINGTON Approach: S			
SCHOOL, EAST	8000	2L/2W	14000	2L/2W	7-D	YES	10000	2L/2W	7-D	YES
SCHOOL, WEST	9000	2L/2W	14000	2L/2W	7-D	YES	10000	2L/2W	7-D	YES

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Figure 29. Example screening

are entered in the appropriate columns - ADTs in columns d and h, the configurations in columns e and i. In this case, both Lexington and School Streets have 2-lane 2-way (2L/2W) configurations.

The next step is to determine which screening curve is appropriate for the specified conditions. Figure 7 provides curves for the analysis of a 2-lane 2-way street (in this case, Lexington Street) in a congested area for signalized intersections. Because School Street is a 2-lane 2-way street, curve D in Figure 7 is selected and this is recorded in colums f and j.

To determine the hot spot potential for the Lexington Street north approach, the point corresponding to 14,000 on the abscissa and 8,000 on the ordinate is plotted in Figure 7. Since this point is above and to the right of curve D, hot spot potential is indicated for the Lexington Street north approach.

SECTION IV

HOT SPOT VERIFICATION

A. INTRODUCTION

Section III presented a screening technique for identifying locations on a highway network where the potential exists for traffic-generated carbon monoxide emissions to exceed the NAAQS for 8-hour average concentrations for the winter of 1982-1983. The screening technique was designed specifically for performing an areawide assessment of an entire city or town using only the most basic data elements and a number of simplifying assumptions. It was stressed that various assumptions used in developing the screening technique were intentionally conservative. As a result, many of the locations identified as potential hot spots by the screening process may, in fact, not be hot spots after all. In order to verify the hot spot potential of a location further analysis is required utilizing a technique that accounts for physical and operational characteristics particular to that location. The purpose of this section, then, is to present a technique for quantifying the hot spot potential at locations where the screening process indicated such potential exists.

B. OVERVIEW OF HOT SPOT VERIFICATION

The verification process is a followup to the screening of an area. Conceptually, the technique involved is identical to that used for the screening. It assumes an explicit relationship between air quality, traffic operating characteristics, and physical characteristics of an intersection, for particular meteorological conditions. Therefore, if both traffic and physical characteristics are determined, and a particular set of meteorological conditions assumed, estimates of the resulting air quality can be made. Again, these estimates are made using a series of curves that relate various traffic and roadway characteristics to resulting air quality.

The purpose of the verification process is to provide a *quantitative estimate* of the highest potential 1-hour and 8-hour average carbon monoxide in the vicinity of the roadway under analysis. Since a worst-case analysis is being performed, it is desirable to maximize the effects of traffic, meteorology, and receptor siting. Thus, the CO concentration estimate should be made using peak hour traffic data, temperatures typical of cold winter days, and low windspeeds (1 m/sec). The concentration curves presented in this section were derived from data presented in References 15 and 16. Concentration estimates are maximized by locking receptor location and wind direction into a worst case configuration for freeways and intersection (see Volume II for rationale).

In discussing the verification process it is necessary to consider the three basic elements of the procedure - these include the data required, the curves to be used, and a set of standard worksheets to be used for performing and recording the verification of potential hot spots.

1. Data Requirements

While in the screening process it was emphasized that maximum use should be made of existing general traffic data, the verification process requires current data specific to each site analyzed. However, existing data may be used if they are determined to be representative of current traffic conditions and of sufficient detail. The required data are outlined below, and summarized in Table 8. *In all cases observed data should supercede suggested estimates herein when these data apply to the locations being modeled.* Specific guidance for estimates is given in the worksheet instructions.

a. Location Sketch - A sketch should be prepared of each location requiring verification. This sketch should show:

Table 8. SUMMARY OF DATA REQUIREMENTS FOR HOT SPOT VERIFICATION

Data element	Remark
Location sketch	The sketch should dimension the traffic engineering features, identify the geometry of the location and identify traffic operational constraints.
Traffic volume	Peak hour volume projected to the analysis year for the busiest winter season month.*
Vehicle speed	Estimate of operating cruise speed.
Receptor separation	The distance between the receptor site and the centerline of the traffic stream.
Vehicle classification	Distribution of traffic by vehicle type: LDV, LDT, HDV-G, HDV-D.
Traffic signal operation	Signal timing and phasing at signalized intersections.
Vehicle mode operation	Distribution of vehicles by operating mode: cold-start, hot-start, stabilized.
Temperature	Ambient temperature representative of winter days.

- the approximate geometry of the location
- the number of approach and departure lanes on each roadway if the site is an intersection, or just the number of lanes if the site is an expressway or mid-block location
- the width of each lane, shoulder, median, and channelizing island
- the locations within each site where curb parking is permitted, where bus stops and taxistands are located, and the width of such parking lanes
- the location of the worst-case receptor site (see part d below)

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*See discussion concerning critical season beginning on page 34.

- pertinent notes regarding observations as to the operation of the facility.

b. Traffic Volume - Peak hour volume data (or projected data) averaged per lane are required for all streets and highways analyzed. These volumes should be representative of the busiest month from November through March. This implies that a statistical data base must also be available from which projections are made. The directional split of peak hour traffic is also required since computations of carbon monoxide concentrations are performed on a traffic stream basis.

While traffic volume data are often the most abundant data generally available, in many instances sufficient data may not exist to perform hot spot verification, and new data will be required. Again, the validity of existing data must be judged. Ideally, the development of all traffic volume data used in the verification process should be accomplished by a competent engineering or planning professional, and may require direction at the state level.

c. Vehicle Cruise Speed - Estimates of the cruise speed of freely flowing vehicles and vehicles departing from signalized intersections must be made. These can be based on actual field studies or through estimates based on observed operating characteristics and surrounding land use. Several figures and tables, which appear later in this section, have been provided to aid in making these estimates.

d. Roadway/Receptor Separation Distance - The separation distance, x, between the receptor site and traffic streams in both directions (for both uninterrupted flow locations and intersections) is required. This is the minimum perpendicular distance in meters from the centerline of the traffic stream to a line parallel to the roadway drawn through the receptor site; that is, the offset distance from the centerline of the traffic stream (all lanes in one direction of travel) to the centerline of an adjacent sidewalk or edge of right-of-way.

For intersections, the receptor is a point defined by the offset distance from the centerline of the traffic stream, and a specified back distance from the intersection. The distance back from the intersection is a function of the queue length that develops. The user is not required to compute the distance nor is he required to compute queue length; rather, empirical relationships between volume demand and queue length are used implicitly so that volume and traffic signal parameters (as will be explained later) are the only inputs required.

e. Vehicle Classification Data - Another data requirement is the distribution of traffic by vehicle type. This is usually developed for specific highway classifications such as expressways, major arterials, minor arterials, etc. The vehicle classifications that should be identified include:

- light-duty vehicles (passenger cars) - LDV
- light-duty trucks (panel and pickup trucks, light delivery trucks - usually all 2-axle, 4-wheel trucks) - LDT
- heavy duty, gasoline-powered trucks - HDV-G
- diesel-powered trucks - HDV-D.
- motorcycles - MC

These data may be available for a community where recent comprehensive transportation planning programs have been accomplished.

f. Traffic Signal Data - A necessary element in the verification of hot spot potential at signalized intersections is the ratio of the green time allocated to each approach, to the total cycle length (G/Cy). This ratio can be determined from records or design plans if the installation is of the fixed-time type but if actuated control is utilized, the ratio must be computed based on the actual peak hour volumes.

Where actuated pedestrian signals are used, estimates should be made of the number of times during the peak hour that the actuated pedestrian phase is called. Also, where turning lanes are provided and these lanes are subject to interference from stopped through traffic, estimates of this interference should be made. The green time allocated to the approaches affected by these occurrences then must be adjusted. (Refer to worksheet for worksheets for guidance in estimating G/Cy.)

g. Percentage of Cold-Start Vehicles - Estimates of the proportion of cold-operating vehicles in the traffic stream during the peak hour are required. This is a difficult statistic to determine for specific locations; therefore it is recommended that a very general approach be taken involving the use of the results of a recently completed study[13] that focused on determining the proportion of cold-operating vehicles in numerous traffic streams in two U.S. cities. This study concluded that the distribution of cold-operating vehicles is a function of the time of day and the type of location. For instance, it was determined that the fraction of vehicles operating in the cold mode during the morning in the CBD was substantially different from the fraction operating at the CBD during the evening; also, the fraction of cold-operating vehicles at locations in the CBD differed significantly from the fraction in say, residential areas for the same time-period. In the absence of data specific to a location undergoing hot spot analysis, it is recommended that the fraction of vehicles operating in the cold mode be estimated using the information in the worksheet instructions.

h. Percentage of Hot-Start Vehicles - The proportion of vehicles operating in the hot-start mode must also be estimated. This parameter, like the cold-mode fraction, is not easily determined. The actual impact of hot-start vehicles is not nearly as significant as the cold-start fraction, however. Again, guidance is provided in estimating this parameter in the worksheets.

i. Temperature - Ambient temperature has a significant effect on the emissions from cold-operating vehicles and the time necessary to achieve normal operating temperature. Colder temperatures produce higher emission rates. Since a worst-case analysis is being performed, a temperature typical of that during the peak traffic hour on cold winter days (or critical season) should be used.

j. Street Canyons - At some midblock locations and intersections in urban areas, a vortex motion may develop in the wind circulation between tall buildings. This occurs in areas referred to as "street canyons." A schematic of this windflow pattern is depicted in Figure 30. A vortex will form when two conditions exist; first, the roadway/wind angle, θ, must be at least 30°, and second, the penetration depth, δ, of the rooftop wind into the street canyon, must be less than the average height, H, of the upwind buildings. In the analysis of hot spots, an assumption can be made outright that the roadway/wind angle is 30°, but the rooftop wind penetration depth must be calculated using the equation:

$$\delta = 7\ (kW/u)^{\frac{1}{2}} \qquad (6)$$

where k = turbulent diffusivity of momentum $\simeq 1\ m^2/sec$

W = street canyon width (building-to-building), m

u = rooftop windspeed, m/sec

7 = an empirical nondimensional constant.

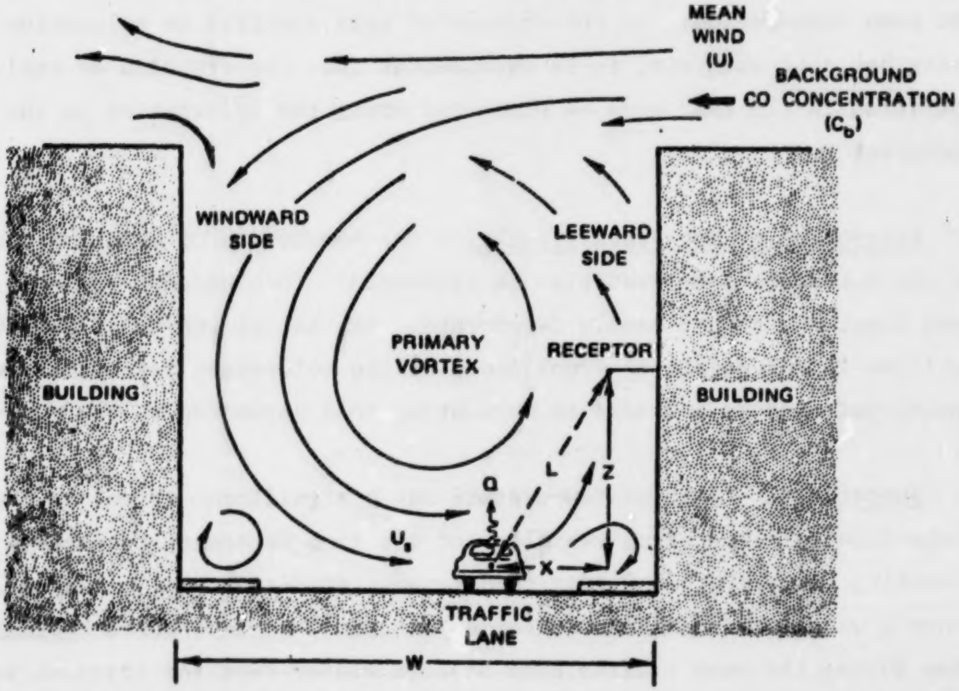
MEAN
WIND
(U)
BACKGROUND
CO CONCENTRATION
(C_b)
WINDWARD
SIDE
LEEWARD
SIDE
PRIMARY
VORTEX
RECEPTOR
BUILDING
BUILDING
Q
L
Z
U_s
X
TRAFFIC
LANE
W

Figure 30. Schematic of cross-street circulation between buildings

Again, in these Guidelines, the criterion for roadway/wind angle can be assumed to be met so that the user must only check the building height and penetration depths.

When the vortex forms, dispersion of CO along roadways is different compared with dispersion along open areas. To reflect these different dispersion characteristics, a separate technique is introduced into this analysis that better describes street canyon dispersion. This is accomplished by introducing the street canyon criterion for penetration depth in the worksheets (again, the roadway/wind angle criterion is assumed to be met), and special procedures are defined throughout if a street canyon situation is indicated.

When applying the street canyon calculations to an intersection, only the main link (determined beforehand) is considered.* Since the CO concentration computed using the street canyon procedure may be lower than if the nonstreet canyon procedure is used, it may be useful in many instances to use both techniques so that hot spot potential can be assessed more completely.

k. Miscellaneous Data - This category includes information relative to planned projects that will directly impact traffic or travel within the study area in the near future. These could involve alteration to the street network, (e.g., adding or deleting major arterials or expressways, revising circulation patterns, changing signal systems, etc.), or the development of programs to create mode shifts, (e.g., improving bus service for commuters). The expected effect on traffic volumes must be considered where these possibilities exist.

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*It is noted that the affects of other nearby links in terms of concentrations at receptors located in a street canyon have not been investigated thoroughly, and thus are assumed at this time to have minimal impact at the receptor.

Another area of consideration is the effect of programs that will have an impact on automotive emissions, such as mandatory inspection and maintenance programs. Where such programs are in effect or are anticipated, their impacts should be estimated.

2. Hot Spot Verification: Process, Assumptions, and Limitations

The hot spot verification process will yield the expected worst-case carbon monoxide concentration in the vicinity of the roadway. The procedure can be summarized as follows for each location:

1. Specify the site-specific traffic and roadway parameters.
2. Determine the optimum receptor placement (instructions follow the worksheets).
3. Determine the emission rates.
4. Apply emission correction factors to account for variability in calendar year, vehicle mix, temperature, altitude, and percent of cold operating vehicles.
5. Determine the normalized concentration contribution of the roadway(s) at the receptor site.
6. Apply the distance correction factors.
7. Apply the 8-hour averaging factor, if appropriate.
8. Add the background carbon monoxide concentration.

Basically, the verification procedure summarized above consists of solving the following equation for the expected peak carbon monoxide concentration for an 8-hour averaging period:

$$\chi_8 = C_8 \left[C_{Ef} \left(\sum_{i=1}^{m} Cd_{fi}\, n_i\, Q_{fi} \left(\frac{\chi u}{Q} \right)_{fi} \right) + C_{Ee} \left(Q_e \sum_{i=1}^{m} Cd_{ei}\, n_i \left(\frac{\chi u}{Q} \right)_{ei} \right) \right] / u + \chi_B$$

where χ_8 = the estimated 8-hour average CO concentration at the receptor;

C_8 = empirical conversion factor to change from a 1-hour averaging time to an 8-hour averaging time;

C_{Ef} = free flow emissions correction factor combining the effects of calendar year, vehicle-mix, altitude, temperature, proportion of cold-operating vehicles, and state (California or non-California);

C_{Ee} = excess emissions correction factor combining the effects of calendar year, vehicle-mix, altitude, temperature, proportion of cold-operating vehicles, and state (California or non-California);

Q_f = the emission rate (g/m-sec) of carbon monoxide from freely flowing traffic;

$(\chi u/Q)_f$ = the normalized concentration (m^{-1}) at the receptor resulting from free-flow emissions;

Cd_f = distance correction factor for the concentration contribution from free flow emissions;

Q_e = the excess emission rate from interrupted flow due to idling, acceleration, and deceleration (g/m-sec);

$(\chi u/Q)_e$ = normalized concentration due to excess emissions from interrupted flow (m^{-1});

Cd_e = distance correction factor for the concentration contribution from excess emissions from interrupted flow;

u = windspeed (m/sec); and

χ_B = background concentration, 8-hour averaging time.

and where

i = approach index

n = number of lanes

m = number of approaches.

The verification procedure utilizes the following assumptions (see Volume II[2] for detailed explanation of assumptions):

$u = 1$ m/sec

$Cd_{f3} = Cd_{f4} = 1$

$Cd_{e} = 0$ for uninterrupted flow

$Cd_{e3} = Cd_{e4} = 1$ for signalized intersections

$Cd_{e3} = Cd_{e4} = 0$ for nonsignalized intersection

$(\chi u/Q)_{f1} = (\chi u/Q)_{f2}$

$(\chi u/Q)_{f3} = (\chi u/Q)_{f4}$

If the receptor is near a roadway with interrrupted flow (signalized or signed intersections), then the entire equation must be solved. If the receptor is located near a roadway where only uninterrupted flow conditions occur, then only the free flow portion of the equation (subscript "f" variables) must be solved and the excess emission terms (subscript "e" variables) within the brackets may be dropped. The worksheets automatically perform this procedure for the different cases. The remainder of this discussion describes each of the variables in this equation. Following this overview, step-by-step instructions, worksheets, tables and curves are discussed in detail.

a. Q_f - Base Emission Rate from Free-Flowing Traffic - The free-flow emission rate, Q_f (g/m-sec), is derived from the average vehicle cruise speed, S, and traffic volume, V, based upon 1977 emission rates of light-duty vehicles at specified ambient conditions. Average vehicle cruise speed may be determined by observation or estimated from the type of roadway and surrounding land use (see Table 13 and Figures 39 and 40). Values of Q_f are tabulated in Table 10 in the detailed instructions on applying the verification procedures as a function of hourly lane volume and cruise speed. These were developed from application of the Modal Model.[7]

b. Q_e Excess Emission Rate From Delayed Traffic - At locations where interrupted flow occurs (signalized and signed intersections), excess emissions above cruise emissions result from idling, acceleration, and deceleration. The excess emissions rate, Q_e (g/m-sec), is a function of acceleration and deceleration, the vehicle cruise speed, S, and the time of delay at the intersection. Delay time is a function of the relative traffic volumes, V, on the two intersecting streets and the G/Cy ratio (at signalized intersections).

The Modal Model was again used here for developing the emissions characteristics for both STOP-sign controlled and signalized intersections that are utilized in the verification procedure. In applying these relationships, the actual volume on the street being analyzed, and the *effective crossroad volume* are used. Effective crossroad volume refers to a theoretical volume that reflects total impedance to the free flow of traffic resulting from the allocation of free signal time to cross-street traffic. This will be explained more fully in the instructions for conducting the verification analysis.

Appropriate values for Q_e are computed in step 17 of Worksheet No.5.

c. C_{Ee} and C_{Ef} - Excess and Free-Flow Emission Correction Factors - The emission rates, Q_e and Q_f, from the Modal Model[7] reflect 1977 composite emission rates of light-duty vehicles at specified ambient conditions. Those are the base emissions used in the guidelines. To quantify the hot spot potential at a specific location, corrections must be made to both free flow and excess emission rates to account for the actual calendar year emission rates and the effects of actual vehicle mix, temperature, altitude, percent cold-start operation, percent hot-start operation, and state (California or other).

Correction factors for both the free-flow and excess emission components are computed separately based on Mobile I.[8]* These correction factors, C_i, are summarized in Table 12. They are derived by taking the ratio of the emissions of individual vehicle types at variable cold start, speed, etc., to the emissions for a 1977, 100 percent LDV population at specified base conditions. These correction factors by vehicle type are then multiplied by the proportion of each vehicle type, summed, multiplied by the Modal emissions estimate, Q_e and/or Q_f. The general equation for calculating the entire emission correction factor is:

$$C_E = \sum_{i=1}^{5} (P_i C_i)$$

where P_i = the proportion of vehicle type i (i.e., LDV, LDT, etc.); and

$C_i = \frac{E_V}{E_B}$ = the basic correction factor provided in the Guidelines to account for the fraction of vehicle type i's operating in the cold or hot start mode, the calendar year of interest, and travel speed; and

where E_V = Mobile I[8] emission factor for desired scenario; and

E_B = Mobile I[8] emission factor for the base conditions of the Modal Model.[7]

Calculation of the specific correction factors for cruise and excess emissions is explained in greater detail in the instructions for conducting the verification process. If the critical season temperature is different from those presented in the table, appropriate values can be derived through interpolation or extrapolation.

d. χu/Q - Normalized Concentrations - This term is a measurement of the atmospheric dispersion of a pollutant as a function of windspeed and direction (with respect to the emission source and receptor), and the distance separating the source and receptor. At intersections, two normalized concentration terms are important. First, the normalized concentration for the excess emission component (that is, emissions generated from vehicles that accelerate, decelerate and idle at the intersection), must be considered. This term, designated as $(\chi u/Q)_e$, is a function of vehicle queue and delay parameters as well as windspeed and direction parameters and source-receptor separation. In most instances, the CO concentration at a receptor is maximized when $(\chi u/Q)_e$ from the nearest street approach is maximized.

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*No option for other scenarios exists in the Modal Model,[7] hence the use of the Mobile I[8] emission factors.

The second term, $(\chi u/Q)_f$, is the normalized concentration occurring at a receptor that results from the emissions generated by vehicles that move through the intersection without significant slowdowns, that is, the free-flowing traffic.

The analysis of intersections requires both the $(\chi u/Q)_e$ and $(\chi u/Q)_f$ for all approaches. To derive these values, the approach volume and cruise speed for the approach being analyzed, and the effective crossroad volume are utilized to derive a queue length; this is accomplished through the use of tables provided in the guidelines. This queue length is then utilized to derive $(\chi u/Q)_e$ for all approaches based on functional relationships defined graphically in the guidelines.

e. Source-Receptor Separation Distance Correction Factors - The normalized concentration values from both excess and free-flow emissions that the user obtains from the graphs provided in the guidelines, reflect standard source-receptor separation distances of 10 meters and 15 meters. Obviously, this separation distance will not be appropriate for all locations, therefore correction factors - Cd_e and Cd_f - are provided so that the normalized concentrations from both the excess and free flow source emissions can be adjuted to reflect the actual source-receptor separation distance. These adjustments are made only to traffic passing over the street section adjacent to the receptor (cross-street distances are large enough that relatively small differences do not effect the normalized concentration values significantly). Also, it should be noted that a factor of 1.0 is used in analyses of street canyons.

f. C_8 hr - 8-Hour Correlation Factor - The verification procedures incorporate techniques based upon the calculation of 1-hour average concentrations of carbon monoxide from peak hour traffic volumes. Because the 8-hour standard is more often violated than the 1-hour standard, it is necessary to provide a means for developing estimates of the 8-hour average concentration from the calculated 1-hour average.

Analyses of air quality data from a number of monitoring stations in several cities in the northeastern U.S. were conducted in order to determine whether a definite relationship could be established between 1-hour average and 8-hour average concentrations. These analyses were based on examining the relationship between maximum 1-hour average concentrations, and maximum 8-hour average concentrations where the 8-hour averaging period included the maximum 1-hour average. These analyses indicated that the average ratio of 8-hour average concentrations to 1-hour average concentrations ranged in value from about 0.5 to 0.8, with an average of about 0.7. Further analysis of these rations with 1-hour concentrations greater than or equal to 10 ppm indicated that this ration was slightly lower with a range generally of from 0.6 to 0.7. Thus, a value of 0.7 was selected as being representative of the 8-hour to 1-hour ratio.[18,19]

g. χ_B - Background Concentration - Studies have indicated the existence of a background concentration of carbon monoxide occurring throughout urban and suburban areas as a result of dispersion at or near ground level. Determination of the actual value of the maximum expected background concentration involves long-term monitoring as described in References 16 and 20. The user is advised to use local measured background concentrations wherever and whenever they are available. For cases where local monitoring is not available a value representing a worst-case background concentration is presented. It is based on limited analyses of data for three cities in New England and on air quality modeling using the EPA diffusion model (APRAC) with meteorological data covering a 1-year period. These analyses indicated that the average maximum background concentration (8-hour average) computed for 20 locations in each city ranged from 2.9 mg/m^3 to 5.9 mg/m^3 during 1973 to 1974.[18,19]

Extrapolating these figures to 1982-1983 would result in a range of 1.7 mg/m^3 to 2.9 mg/m^3. The higher value, 2.9 mg/m^3, yields a conservative estimate of the maximum 8-hour average background concentration. This value should be used *unless data are available to develop specific local background estimates or adjust this value to local conditions.*

C. WORKSHEETS AND INSTRUCTIONS FOR HOT SPOT VERIFICATION

The following pages present detailed instructions for performing hot spot verification. Included are separate worksheets and instructions for analyzing signalized intersections, STOP-sign controlled intersections, free-flowing sections of arterial streets, and expressways. It is suggested that all signalized intersections be analyzed first, followed by analyses of free-flowing arterials and expressway sections, and finally, STOP-sign controlled intersections.

The first step in the process is to assemble the data required regarding volume, vehicle type distribution, percent of vehicles operating in the cold mode, etc., and a site sketch showing street geometry and dimensions as well as the assumed receptor location (the required data elements are discussed in detail in Section IV.V.1). Worksheets No. 5 and 6 are then used to compute the likely maximum concentration based on the various data elements and the relationships presented in Tables 9 through 12, and the graphs shown in Figures 31 through 37. Worksheets No. 5 and 6 are each followed by detailed instructions for completing each line on the Worksheet.

WORKSHEET NO. 5

1 of 3

CALCULATION OF CO CONCENTRATIONS AT INTERSECTIONS

Location: ______________________________ **Date:** ____________

Analysis by: ______________________________ **Checked by:** ____________

Assumptions:
- Analysis Year: ____________.
- Location: (a) _____ California; (b) _____ 49-State, low altitude; (c) _____ 49-State, high altitude.
- Ambient temperature: ___ °F.
- Percent of vehicles operating in: (a) cold-start mode_____; (b) hot-start mode _____.
- Vehicle-type distribution: LDV___%; LDT___%; HDV-G___%; HDV-D___%; MC___%.

	Main road		Crossroad	
1. Site identification				
2. a. i - intersection approach identification	1__	2__	3__	4__
b. Is approach located in a street canyon?				
3. n_i - Number of traffic lanes in approach i				
4. x_i - Roadway/receptor separation (m)			X	X
5. V_i - Peak-hour lane volume in each approach (veh/hr)				
6. S_i - Cruise speed (mph) on each approach				
7. a. Type of intersection (signalized or unsignalized)				
b. For signalized intersections:				
i) $(G/Cy)_1$ - Green time/signal cycle ratio for approach 1		X	X	X
ii) V_{cross} - Effective crossroad volume (veh/hr)	X	X		
8. Le - Queue length on approach 1 (m)		X	X	X

	Main road		Crossroad	
9. Qf_i - Free-flow emission rate (g/m-sec)				
10. $\frac{\chi u}{Q}_{f,main}$ - Normalized concentration contribution from free-flow emissions on main roadway (10^{-3} m^{-1})			☒	☒
11. $\frac{\chi u}{Q}_{f,cross}$ - Normalized concentration contribution from free-flow emission on crossroad (10^{-3} m^{-1})	☒	☒		
12. Cdf_i - Distance correction factor, free-flow emissions			☒	☒
13. C_{Ef} - Emissions correction factor, free-flow emissions.				
14. a. $\chi_{f,main}$ - Concentration contribution from free-flow emissions on main road (mg/m^3)			☒	☒
b. $\chi_{f,cross}$ - Concentration contribution from free-flow emissions on crossroad (mg/m^3)	☒	☒		
15. χ_f - Total concentration from free-flow emissions (mg/m^3)				
16. C_{Ee} - Emissions correction factor, excess emissions				
17. Q_e - Excess emission rate (g/m-sec)				
18. $\frac{\chi u}{Q}_{e,i}$ - Normalized concentration contribution from excess emissions on approach i ($10^{-3}m^{-1}$)				
19. Cde_i - Distance correction factor, excess emissions				
20. $\chi_{e,i}$ - Concentration contribution from excess emissions on approach i (mg/m^3)				
21. χ_e - Total contribution from excess emissions (mg/m^3)				
22. $\chi_{E,1\text{-}hr}$ - 1-hour average concentration resulting from vehicle emissions (mg/m^3)				

23. $\chi_{E,\,8\text{-hr}}$ - 8-hour average CO concentration (mg/m^3) ______________________

24. $\chi_{B,8\text{-hr}}$ - 8-hour average background concentration (mg/m^3) ______________________

25. $\chi_{T,8\text{-hr}}$ - Total CO concentration, 8-hour average (mg/m^3) ______________________

26. $\chi_{T,8\text{-hr}}$ - Total CO concentration, 8-hour average (ppm) ______________________

WORKSHEET NO. 5

INSTRUCTIONS FOR COMPLETING EACH LINE

I. HEADING DATA

Location: Enter intersection street name

Date: Enter date of analysis.

Analysis by: Enter name of person performing analysis.

Checked by: Enter name of person checking the completed Worksheet.

Assumptions: Analysis year - enter calendar year reflected by the analysis.

Location - place an X on the appropriate line indicating the type of location being considered (low altitude is < 3500 ft).

Ambient Temperature - enter the assumed average winter temperature for the area being considered (either 20°F or 40°F).

Percent of Vehicles - enter the proportion of vehicles operating in the cold-start mode and the proportion in the hot-start mode (see Section IV.D.3).

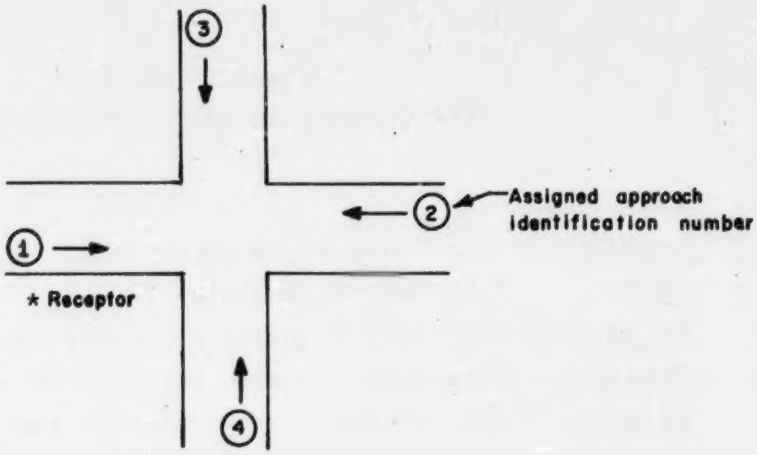
Vehicle-type distribution - enter the percentages of light-duty vehicles, light-duty trucks, heavy-duty gasoline-powered trucks, heavy-duty diesel-powered trucks, and motorcycles that use the streets being analyzed (use one set of percentages).

II. COMPUTATIONS

1. Enter the main street and cross-street names (refer to site sketch). The main street will always be the street adjacent to the receptor. In this connection, the assumed receptor location should be at the point where the maximum projected concentration is likely to occur. Guidance for identifying this point is provided in the Special Instructions found in Section IV.D beginning on page 167.

2. a. Intersection approach identification numbers should be added to the site sketch for reference. The designations should be made according to the sketch as shown.

   b. Enter "yes" or "no" for each approach. Guidance in identifying street canyons is provided in Section IV.B.1.j beginning on page 104. If approach 1 is in a street canyon, then use the street canyon options indicated throughout the instructions that follow.



Note that approach ① is adjacent to the receptor, ② is on the leg opposite approach ①, ③ intersects ② before it intersects ①, and ④ intersects ① before it intersects ②. Again, refer to page 167.

3. Enter the number of lanes (omitting parking lanes) for each approach (from site sketch).

4. Enter the roadway/receptor separation distance, x_i, for approaches 1 and 2. This is the minimum perpendicular distance in meters from the centerline of the traffic stream approaching the intersection to a line parallel to the roadway drawn through the receptor site (see site sketch).

5. Enter the peak-hour lane volume, V_i (vehicles/hour), for each intersection approach. This is the total traffic stream volume divided by the number of approach lanes recorded on line 3. This should represent the busiest winter month* average weekday volume for the year of interest (based on traffic volume data).

6. Enter the estimated roadway cruise speed, S_i (mph), for each approach (see Section IV.D.2 on page 174 for guidance).

7. a. Enter type of intersection (signalized, unsignalized).

   b. For signalized intersections (for nonsignalized intersections proceed to next step):

      (i) Enter the ratio of green time to total signal cycle length $(G/Cy)_1$ allocated to approach 1. Include time allocated for any pedestrian walk phases with no traffic movement in the total cycle length. For fixed time signals, this data will be available from design specifications or from permits and records maintained by the agency having jurisdiction over the signal. For actuated

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[*] This assumes that winter is the critical season for CO. If it is determined that some other season is in fact the critical season, then the corresponding traffic volumes and ambient temperature should be used.

signals, the G/Cy for approach i can be estimated from the equation:

$$G/Cy_i = \frac{0.9\ Vmax_i}{\sum_{i=1}^{n} V\ max}$$

where G/Cy_i is the G/Cy for approach i; and

Vmax is the highest hourly lane volume that occurs on all approaches where traffic moves during phase i.

(ii) Determine the effective crossroad volume, V_{cross}, for approach 1 using the following equation and the volume from line 5 if the signal is fixed time:

$$V_{cross} = \frac{\text{line } 5_1}{\text{line } 7.b.i + 0.05} - \text{line } 5_1$$

for actuated signals, V_{cross} = the highest volume in line 5_3 and 5_4.

8. Determine the queue length, Le (m), that develops on approach 1 as follows:

   For signalized intersections enter the appropriate section of Table 9 based on cruise speed S_1 (line 6). Enter the table using $V_{main} = V_1$ (line 5) and V_{cross} = line 7 b-ii.

   For unsignalized intersections use the appropriate section of Table 11 based on cruise speed S_1. Enter the table using $V_{main} = V_1$ (line 5) and $V_{cross} = V_3$ or V_4 (line 5), whichever is greater.

9. Enter the free-flow emission rate, Qf_i (g/m-sec), for each traffic stream using Table 10. Enter the table using line 6i (cruise speed) and line 5 (average lane volume) for each approach. If the street is within a street canyon, enter only the Qf_i for approaches 1 and 2.

10. Enter Figure 34 at the appropriate queue length, Le (line 8), and record the $(\chi u/Q)_f$ main value using the curve designated MAIN ROAD. If the location is within a street canyon, use Figure 35, using line 4_1 and 4_2.

11. Similarly, determine the normalized concentration contribution from free-flow emissions on the crossroad, $(\chi u/Q)_{f,cross}$. Use the CROSSROAD curve of Figure 34. Enter the graph at the same queue length as in step 10. Omit this step for street canyons.

12. Enter the distance correction factors, Cdf_i, for free-flow emissions from the main roadway. Obtain these values from Figure 37.

    a. Cdf_1 is the correction factor at $x = x_1$ (line 4).

    b. Cdf_2 is the correction factor for the departure lanes on leg 1, evaluated at x = the roadway/receptor separation distance for the departure stream. This value is x_2 (line $4)_2$.

Note: For street canyons, assume a value of 1.0.

13. Compute the free-flow emissions correction factor, C_{Ef}, reflecting the assumed calendar year, cruise speed, percentage of vehicles operating in the cold-start and hot-start modes, ambient temperature, and vehicle-type distribution. This is derived from the following equation:

$$C_{Ef} = P_{LDV}\,C_{LDV} + P_{LDT}\,C_{LDT} + P_{MC}\,C_{MC} + P_{HDG}\,C_{HDG} + P_{HDD}\,C_{HDD}$$

where P_{LDV} = fraction of light-duty vehicles (from heading data);

P_{LDT} = fraction of light-duty trucks (from heading data);

P_{MC} = fraction of motorcycles (from heading data);

P_{HDG} = fraction of heavy-duty, gasoline-powered trucks (from heading data);

P_{HDD} = fraction of heavy-duty, diesel-powered trucks (from heading data);

C_{LDV} = correction factor reflecting the assumed calendar year, cruise speed, percentage of vehicles operating in the cold start mode, percentage of vehicles operating in the hot-start mode, and ambient temperature for light-duty vehicles (obtained from Table 12);

C_{LDT} = correction factor reflecting the assured calendar year, cruise speed, percentage of vehicles operating in the cold-start mode, percentage of vehicles operating in the hot-start mode, and ambient temperature for light-duty trucks (obtained from Table 12);

C_{MC} = correction factor reflecting the assumed calendar year, cruise speed, percentage of vehicles operating in the cold-start mode, percentage of vehicles operating in the hot-start mode, and ambient temperature for motorcycles (obtained from Table 12);

C_{HDG} = correction factor reflecting the assumed calendar year and cruise speed for heavy-duty, gasoline-powered trucks (obtained from Table 12);

C_{HDD} = correction factor reflecting the assumed calendar year and cruise speed for heavy-duty, diesel-powered trucks (obtained from Table 12).

14. Compute the concentration contribution from free-flow emissions, χ_f, from each roadway

a. $$\chi_{f,\mathrm{main}} = \Big[(\text{line } 10)(\text{line } 13)\Big]\Big[(\text{line } 3)_1(\text{line } 9)_1(\text{line } 12)_1 + (\text{line } 3)_2(\text{line } 9)_2\,(\text{line } 12)_2\Big]$$

b. $\chi_{f_{cross}} = \left[(\text{line }11)(\text{line }13)\right]\left[(\text{line }3)_3(\text{line }9)_3 + (\text{line }3)_4\ (\text{line }9)_4\right]$

Note: for street canyons, $\chi_{f,cross}$, need not be computed.

15. Sum line 14a and 14b entries to obtain total contribution from free-flow emissions, χ_f.

16. Compute the excess emissions correction factor, C_{Ee}, reflecting the assumed calendar year, idle (speed 0), percentage of vehicles operating in the cold- or hot-start mode, ambient temperature, and vehicle type distribution. This is derived from the following equation:

$$C_{Ee} = P_{LDV}\ C_{LDV-O} + P_{LDT}\ C_{LDT-0} + P_{MC}\ C_{MC-0} + P_{HDG}\ C_{HDG-0} + P_{HDD}\ C_{HDD-0}$$

where P_{LDV}, P_{LDT}, P_{MC}, P_{HDG} and P_{HDD} are as defined in item 13, above; and

C_{LDV-0}, C_{LDT-0}, C_{MC-0}, C_{HDG-0}, and C_{HDD-0} are the correction factors from Table 12 reflecting the assumed calendar year, speed of 0, percentages of cold- and hot-start operation, and ambient temperature for each vehicle type.

17. Compute the excess emission rate, Q_e (g/m-sec), from:

$$Q_e = (Q_{QT})\ (C_{Ee}) - (Q_{QC})\ (C_{Ef})$$

where Q_{QT} = the total queue emission rate found in Table 9 for signalized intersections or Table 11 for nonsignalized intersection;

Q_{QC} = the cruise component of the queue emissions, also found in Table 9 for signalized intersections and Table 11 for nonsignalized intersections;

C_{Ee} = the excess emissions correction factor found in item 16, above; and

C_{Ef} = the free-flow emissions correction factor found in item 13, above.

To use Tables 9 or 11, the highest main road lane volume from line 5 and the effective crossroad volume, V_{CROSS}, from line 7.6.ii are used. Interpolation should be performed as required in using the tables.

18. Determine the normalized concentration contribution from excess emissions, $(\chi u/Q)_{e,i}$ for each approach as follows:

a. The contribution from approach 1:
Enter Figure 31 at the appropriate queue length, Le (line 8), to obtain $(\chi u/Q)_{e,1}$. Multiply this value by the number of traffic lanes in approach 1 (line 3), and record result. For street canyons, the procedure is the same except use Figure 35 instead of 31.

b. The contribution from approach:
Enter Figure 32, curve 2, at the same Le, used in part (a), (line 8), to obtain $(\chi u/Q)_{e,2}$. Multiply this value by the number of traffic lanes in approach 2 (line 3), and record result. For street canyons, assume $(\chi u/Q)_{e,2} = 0$.

c. The contribution from approach 3:
Signalized intersections - Enter Figure 32, Curve 3 at Le (line 8) to obtain $(\chi u/Q)_{e,3}$. Multiply by the number of traffic lanes in approach 3 (line 3), and record result. For street canyons and unsignalized intersections, $(\chi u/Q)_{e,3} = 0$.

d. The contribution from approach 4:
Signalized intersections - Enter Figure 32, Curve 4 at Le (line 8) to obtain $(\chi u/Q)_{e,4}$. Multiply by the number of traffic lanes in approach 4 (line 3) and record result. For street canyons and unsignalized intersections, $(\chi u/Q)_{e,4} = 0$.

19. Determine the distance correction factors for the excess emissions contributions, Cde_i:

a. Approach 1: obtain Cde_1 from Figure 36 at the appropriate roadway/receptor separation distance x_1 (line 4).
Note: For street canyons, $Cde_1 = 1.0$.

b. Approach 2: compute Cde_2 by dividing the value obtained from Figure 36 at the appropriate distance x_2 (line 4) by 0.79:

$$Cde_2 = \frac{Cde\ (\text{at } x_2)}{0.79}$$

c. Approach 3&4: $Cde_{3,4} = 1$ for signalized intersections and $Cde_{3,4} = 0$ for nonsignalized intersections.

20. Compute the concentration contribution from excess emissions, χ_e, for each approach i, using the following equation:

$$\chi_{ei} = (Q_E)\left(\frac{\chi u}{Q}\right)_{ei}(Cde)_i$$

where Q_E = the excess emission rate from line 17;

$\left(\frac{\chi u}{Q}\right)_{ei}$ = the normalized concentration contribution from excess emissions from line 18; and

$\left(Cde\right)_i$ = the distance correction from line 19.

21. Sum all line 20 entries to obtain the total concentration, χ_e, resulting from excess emissions at the intersection.

22. Compute the 1-hour average concentration resulting from vehicle emissions, $\chi_{E,\ 1\text{-hour}}$, by summing line 21 and line 15.

23. Multiply line 22 by 0.7 to obtain the highest expected 8-hour average concentration resulting from vehicle emissions.

24. Enter 8-hour average background CO concentration in mg/m^3. Use 2.9 mg/m^3 if specific local background estimates are not available and see Section V.B.

25. Sum lines 23 and 24 to obtain maximum expected 8-hour average concentration in the vicinity of the intersection (mg/m^3).

26. Multiply line 25 by 0.87 to convert the CO concentration from mg/m^3 to ppm.

WORKSHEET NO. 6

CALCULATION OF CO CONCENTRATIONS ALONG ROADWAYS WHERE UNINTERRUPTED FLOW PREVAILS

Location: ______________________________ Date: ______________

Analysis by: ___________________________ Checked by: ______________

Assumptions:
- Analysis Year: _________.
- Location: (a)_______ California; (b) ______49-State, low altitude; (c)______49-State, high altitude.
- Ambient temperature: _______ ^{o}F.
- Percent of vehicles operating in: (a) cold-start mode_____%; (b) hot-start mode________%.
- Vehicle-type distribution: LDV ____%, LDT ____%; HDV-G____%; HDV-D____; MC____%.
- Street Canyon: _____ Yes; _____ No.

1. Site identification		
2. Traffic stream identification	1 __	2 __
3. V_i - Peak-hour lane volume for each traffic stream (veh/hr)		
4. x_i - Roadway/receptor separation (m)		
5. n_i - Number of lanes per traffic stream		
6. S_i - Cruise speed (mph) for each traffic stream		
7. Q_{fi} - Free-flow emission rate (g/m-sec)		
8. $\left(\frac{\chi u}{Q}\right)_{f,i}$ - Normalized concentration contribution from each traffic stream (10^{-3} m^{-1})		
9. C_{Ef} - Emission correction factor		
10. χ_i - Concentration contribution from each traffic stream (mg/m^3)		

Worksheet No. 6 (continued).

11. χ_{E}, 1-hr - 1-hour average CO concentration resulting from vehicle emissions (mg/m^3) ____________

12. χ_{E}, 8-hr - 8-hour average CO concentration (mg/m^3) ____________

13. χ_{B}, 8-hr - 8-hour average background concentration (mg/m^3) ____________

14. χ_{T}, 8-hr - Total CO concentration, 8-hour average (mg/m^3) ____________

15. χ_{T}, 8-hr - Total CO concentration, 8-hour average (ppm) ____________

WORKSHEET NO. 6

INSTRUCTIONS FOR COMPLETING EACH LINE

I. HEADING DATA

Location: Enter facility name and general location (e.g., Mystic Parkway between exits 60 and 61).

Date: Enter date of analysis.

Analysis by: Enter name of person performing analysis.

Checked by: Enter name of person checking the completed Worksheet

Assumptions: Analysis year - enter calendar year reflected by the analysis.

Location - place an X on the appropriate line indicating the type of location being considered (low altitude is < 3500 ft).

Ambient Temperature - enter the assumed average winter temperature for the area being considered (either 20°F or 40°F).

Percent of Vehicles - enter the proportion of vehicles operating in the cold-start mode and the proportion in the hot-start mode (see Section IV.D.3 on page 174).

Vehicle-type distribution - enter the percentages of light-duty vehicles, light-duty trucks heavy-duty gasoline-powered trucks, heavy-duty diesel-powered trucks, and motorcycles that use the streets being analyzed (use one set of percentages).

Street Canyon: place an X on the appropriate line (see Section IV.B.1 on page 104 for guidance in identifying street canyons).

II. COMPUTATIONS

1. Enter the facility name.

2. Enter the direction of flow for each traffic stream (e.g., northbound, eastbound, etc.). Again, approach 1 shall be adjacent to the assumed receptor.

3. Enter the peak-hour traffic volume, V_i, for each traffic stream (winter, busiest month, estimates or observed).

4. Enter the traffic stream/receptor separation distance, x_i. This is the perpendicular distance in meters from the centerline of each traffic stream to the receptor location. Minimum distance = 10 meters.

5. Enter the number of lanes, n_i, per traffic stream (see site sketch).

6. Enter the average cruise speed, S_i (mph), for each traffic stream (for guidance, see Section IV.D.).

7. Determine the free-flow emission rate, Qf_i (g/m-sec), for each traffic stream from Table 9. Enter the table using line 6, cruise speed and (line 3) ÷ (line 5), average lane volumes.

8. Determine the normalized concentration contribution $(\chi u/Q)_{f,i}$ from each traffic stream using Figure 33. Enter the graph at the appropriate roadway/receptor separation distance x_i (line 4). If the facility is located within a street canyon, use Figure 35.

9. Compute the free-flow emissions correction factor, C_{Ef}, reflecting the assumed calendar year, cruise speed, percentage of vehicles operating in the cold-start mode, percentage of vehicles operating in the hot-start start mode, ambient temperature, and vehicle-type distribution; C_{Ef} is derived using the equation shown in Item 13 of the instruction sheet explaining Worksheet No. 5.

10. Compute the concentration contribution, χ_i, from each stream as follows:

$$\chi_i = (\text{line } 7)_i \ (\text{line } 8)_i \ (\text{line } 9)$$

11. Compute the 1-hour average CO concentration resulting from vehicle emissions by summing the line 10 concentrations.

12. Multiply line 11 by 0.7 to obtain the highest expected 8-hour average concentration resulting from vehicle emissions (mg/m^3).

13. Enter the 8-hour average background CO concentration in mg/m^3. Use the 2.9 mg/m^3 if specific local background estimates are not available.

14. Sum line 15 and line 16 to obtain the maximum expected 8-hour average concentration in the vicinity of the roadway (mg/m^3).

15. Multiply line 17 by 0.87 to convert total CO concentration to ppm.

Table 9. TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 15 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04181	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00013	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05161	0.04023	0.03504	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00004	0.00030	0.00020	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.6	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.04837	0.03873	0.03415	0.03081	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00019	0.00050	0.00043	0.00024	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04562	0.3732	0.03331	0.03029	0.02765	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00039	0.00073	0.00068	0.00050	0.00027	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04262	0.03601	0.03253	0.02980	0.02736	0.02504	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00065	0.00099	0.00094	0.00077	0.00055	0.00028	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.04005	0.03481	0.03181	0.02933	0.02706	0.02488	0.02274	-	-	-	-	-	-
	Q_{QC}	-	0.00096	0.00127	0.00123	0.00106	0.00083	0.00058	0.00030	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.03775	0.03373	0.03114	0.02888	0.02676	0.02470	0.02268	0.02065	0.01003	-	-	-	-
	Q_{QC}	-	0.00130	0.00158	0.00153	0.00136	0.00113	0.00087	0.00060	0.00030	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (QQC), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 15 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.03470	0.03278	0.03051	0.02842	0.02643	0.02449	0.02258	0.02066	0.01870	0.00852	-	-	-
	Q_{QC}	-	0.00163	0.00191	0.00184	0.00166	0.00143	0.00118	0.00090	0.00061	0.00031	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.04536	0.02602	0.03192	0.02988	0.02793	0.02605	0.02423	0.02243	0.02062	0.01878	0.01686	0.00789	-	-
	Q_{QC}	0.00051	0.00159	0.00226	0.00217	0.00198	0.00174	0.00148	0.00121	0.00092	0.00062	0.00032	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	486.0	1107.7	-	-	-
500	Q_{QT}	0.02441	0.02006	0.02561	0.02921	0.02736	0.02559	0.02388	0.02220	0.02051	0.01880	0.01701	0.01512	0.00694	-
	Q_{QC}	0.00084	0.00154	0.00216	0.00250	0.00230	0.00205	0.00179	0.00151	0.00123	0.00093	0.00063	0.00032	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.4	137.9	193.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.01302	0.01568	0.02038	0.02540	0.02665	0.02499	0.02341	0.02186	0.02033	0.01876	0.01712	0.01538	0.01347	0.00492
	Q_{QC}	0.00082	0.00146	0.00202	0.00253	0.00261	0.00236	0.00209	0.00181	0.00153	0.00124	0.00094	0.00064	0.00032	-
	Queue	40.0	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.00851	0.01216	0.01579	0.01948	0.02351	0.02418	0.02276	0.02139	0.02004	0.01867	0.01722	0.01566	0.01393	0.01196
	Q_{QC}	0.00078	0.00134	0.00182	0.00225	0.00267	0.00265	0.00238	0.00210	0.00181	0.00153	0.00126	0.00094	0.00064	0.00032
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.00601	0.00893	0.01142	0.01392	0.01666	0.01984	0.02187	0.02077	0.01968	0.01857	0.01739	0.01608	0.01460	0.01284
	Q_{QC}	0.00071	0.00117	0.00153	0.00186	0.00218	0.00250	0.00262	0.00234	0.00206	0.00178	0.00150	0.00122	0.00093	0.00063
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00384	0.00544	0.00686	0.00838	0.01012	0.01217	0.01464	0.01768	0.01937	0.01870	0.01795	0.01708	0.01601	0.01465
	Q_{QC}	0.00056	0.00086	0.00109	0.00130	0.00151	0.00172	0.00195	0.00219	0.00221	0.00194	0.00168	0.00141	0.00115	0.00088
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 20 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04199	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00016	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05146	0.4065	0.03532	0.1812	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00004	0.00036	0.00025	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.04863	0.03943	0.03475	0.03116	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00023	0.00061	0.00053	0.00030	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04598	0.03834	0.03626	0.03100	0.02803	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00049	0.00089	0.00083	0.00062	0.00033	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04354	0.03739	0.03386	0.03089	0.02812	0.02544	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00081	0.00121	0.00116	0.00095	0.00067	0.00035	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.04139	0.03660	0.03354	0.03082	0.02823	0.02569	0.02316	-	-	-	-	-	-
	Q_{QC}	-	0.00118	0.00157	0.00151	0.00130	0.00103	0.00071	0.00036	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.03959	0.03596	0.03329	0.03078	0.02834	0.02593	0.02352	0.02108	0.01003	-	-	-	-
	Q_{QC}	-	0.00161	0.00195	0.00188	0.00167	0.00139	0.00108	0.00073	0.00038	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street efective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 20 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.03699	0.03547	0.03309	0.03075	0.02844	0.02615	0.02385	0.02152	0.01914	0.00852	-	-	-
	Q_{QC}	-	0.00201	0.00236	0.00227	0.00205	0.00177	0.00145	0.00111	0.00075	0.00038	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.04606	0.02826	0.03510	0.03292	0.03070	0.02850	0.02631	0.02412	0.02191	0.01965	0.01730	0.00789	-	-
	Q_{QC}	0.00063	0.00196	0.00279	0.00267	0.00243	0.00215	0.00183	0.00149	0.00113	0.00077	0.00039	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	484.0	1107.7	-	-	-
500	Q_{QT}	0.02559	0.02222	0.02864	0.03272	0.03058	0.02847	0.02639	0.02432	0.02224	0.02011	0.01790	0.10557	0.00694	-
	Q_{QC}	0.00103	0.00189	0.00266	0.00308	0.00283	0.00253	0.00220	0.00186	0.00151	0.00115	0.00078	0.00039	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.4	137.0	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.01416	0.01773	0.02322	0.02896	0.03032	0.02830	0.02634	0.02441	0.02247	0.02050	0.01844	0.01627	0.01393	0.0492
	Q_{QC}	0.00100	0.00180	0.00248	0.00312	0.00321	0.00290	0.00257	0.00223	0.00188	0.00152	0.00116	0.00078	0.00040	-
	Queue	40.4	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.00960	0.01404	0.01835	0.02264	0.02726	0.02790	0.02609	0.02434	0.02259	0.02081	0.01896	0.01698	0.01483	0.01242
	Q_{QC}	0.00096	0.00166	0.00224	0.00277	0.00328	0.00326	0.00292	0.00238	0.00223	0.00188	0.00152	0.00116	0.00078	0.00040
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.00701	0.01056	0.01357	0.01653	0.01972	0.02335	0.02555	0.02405	0.02258	0.02107	0.01949	0.01779	0.01590	0.01373
	Q_{QC}	0.00087	0.00143	0.00189	0.00229	0.00268	0.00308	0.00323	0.00288	0.00254	0.00219	0.00184	0.00150	0.00114	0.00078
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00463	0.00644	0.00839	0.01021	0.01224	0.01459	0.01738	0.02075	0.02267	0.02143	0.02031	0.01906	0.01762	0.01589
	Q_{QC}	0.00069	0.00105	0.00134	0.00160	0.00186	0.00212	0.00240	0.00269	0.00271	0.00239	0.00206	0.00174	0.00142	0.00109
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 25 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04220	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00019	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05152	0.04112	0.03565	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00005	0.00043	0.00030	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.04894	0.04023	0.03545	0.03155	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00027	0.00072	0.00063	0.00036	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04662	0.03951	0.03536	0.03181	0.02846	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00058	0.00106	0.00099	0.00073	0.00039	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04460	0.03899	0.03539	0.03214	0.02901	0.02590	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00096	0.00144	0.00138	0.00113	0.00080	0.00042	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.04294	0.03866	0.03552	0.03254	0.02958	0.02662	0.02364	-	-	-	-	-	-
	Q_{QC}	-	0.00140	0.00186	0.00180	0.00155	0.00122	0.00084	0.00043	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.04170	0.03852	0.03576	0.03298	0.03017	0.02734	0.02448	0.02157	0.01003	-	-	-	-
	Q_{QC}	-	0.00191	0.00232	0.00224	0.00198	0.00165	0.00128	0.00087	0.00045	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 25 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.03963	0.03856	0.03607	0.03344	0.03076	0.02805	0.02530	0.02251	0.01964	0.00852	-	-	-
	Q_{QC}	-	0.00239	0.00280	0.00269	0.00243	0.00210	0.00172	0.00132	0.00090	0.00046	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.04688	0.03084	0.03876	0.03642	0.03390	0.03132	0.02871	0.02608	0.02340	0.02066	0.01782	0.00789	-	-
	Q_{QC}	0.00075	0.00233	0.00331	0.00317	0.00289	0.00255	0.00217	0.00177	0.00135	0.00091	0.00046	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	484.0	1107.7	-	-	-
500	Q_{QT}	0.02694	0.02471	0.03214	0.03676	0.03429	0.03179	0.02928	0.02677	0.02422	0.02162	0.01892	0.01609	0.00694	-
	Q_{QC}	0.00123	0.00225	0.00316	0.00366	0.00336	0.00300	0.00262	0.00221	0.00180	0.00137	0.00092	0.00047	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.4	137.9	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.01548	0.02009	0.02648	0.03305	0.03454	0.03212	0.02972	0.02734	0.02494	0.02250	0.01996	0.01730	0.01445	0.00692
	Q_{QC}	0.00119	0.00214	0.00295	0.00371	0.00382	0.00345	0.00306	0.00265	0.00223	0.00181	0.00138	0.00093	0.00047	-
	Queue	40.0	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.01085	0.01622	0.02129	0.02628	0.03157	0.03218	0.02993	0.02773	0.02552	0.02328	0.02095	0.01850	0.01585	0.01294
	Q_{QC}	0.00114	0.00197	0.00266	0.00329	0.00390	0.00388	0.00347	0.00307	0.00265	0.00223	0.00181	0.00137	0.00093	0.00048
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.00815	0.01245	0.01604	0.01954	0.02324	0.02739	0.02978	0.02783	0.02590	0.02395	0.02192	0.01975	0.01740	0.01475
	Q_{QC}	0.00103	0.00170	0.00224	0.00272	0.00319	0.00365	0.00383	0.00342	0.00301	0.00260	0.00219	0.00178	0.00136	0.00092
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00553	0.00803	0.01015	0.01231	0.01468	0.01738	0.02052	0.02428	0.02604	0.02456	0.02302	0.02135	0.01948	0.01731
	Q_{QC}	0.00082	0.00125	0.00159	0.00191	0.00221	0.00252	0.00285	0.00320	0.00323	0.00284	0.00245	0.00207	0.00168	0.00129
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 30 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04244	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00022	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05159	0.04168	0.03604	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00006	0.00051	0.00035	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.04929	0.04117	0.03626	0.02101	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00032	0.00086	0.00074	0.00042	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	316.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04737	0.04090	0.03665	0.03277	0.02897	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00068	0.00125	0.00117	0.00087	0.00046	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04585	0.04086	0.03718	0.03362	0.03006	0.02644	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00113	0.00170	0.00163	0.00134	0.00094	0.00049	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.0447	0.04188	0.03786	0.03455	0.03117	0.02772	0.02420	-	-	-	-	-	-
	Q_{QC}	-	0.00166	0.00220	0.00212	0.00183	0.00144	0.00099	0.00051	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.04418	0.04153	0.03867	0.03556	0.03232	0.02901	0.02562	0.02215	0.01003	-	-	-	-
	Q_{QC}	-	0.00225	0.00273	0.00264	0.00234	0.00195	0.00151	0.00103	0.00053	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 30 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.04273	0.04221	0.03958	0.03661	0.03349	0.03029	0.02702	0.02367	0.02023	0.00852	-	-	-
	Q_{QC}	-	0.00282	0.00331	0.00318	0.00287	0.00248	0.00203	0.00156	0.00106	0.00054	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.04785	0.03387	0.04307	0.04055	0.03766	0.03463	0.03153	0.02837	0.02515	0.02185	0.01842	0.00789	-	-
	Q_{QC}	0.00088	0.00275	0.00391	0.000374	0.00342	0.00301	0.00256	0.00209	0.00159	0.00108	0.00055	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	484.0	1107.7	-	-	-
500	Q_{QT}	0.02854	0.02763	0.03625	0.04152	0.03866	0.03569	0.03269	0.03976	0.02656	0.02339	0.02012	0.01670	0.00694	-
	Q_{QC}	0.00145	0.00266	0.00373	0.00432	0.00396	0.00355	0.00309	0.00261	0.00212	0.00161	0.00109	0.00055	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.5	137.9	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.01703	0.02287	0.03032	0.03787	0.03951	0.03660	0.03370	0.03079	0.02785	0.02485	0.02175	0.01851	0.01507	0.00492
	Q_{QC}	0.00141	0.00252	0.00349	0.00438	0.00451	0.00407	0.00361	0.00313	0.00264	0.00214	0.00162	0.00110	0.00045	-
	Queue	40.0	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1108.2	-
300	Q_{QT}	0.01233	0.01878	0.02475	0.03056	0.03664	0.03722	0.03445	0.03171	0.02897	0.02618	0.02330	0.01019	0.01707	0.01356
	Q_{QC}	0.00134	0.00232	0.00314	0.00389	0.00461	0.00458	0.00410	0.00362	0.00313	0.00264	0.00213	0.00162	0.00110	0.00056
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.00949	0.01466	0.01896	0.02308	0.02738	0.03214	0.03477	0.03229	0.02982	0.02733	0.02477	0.02207	0.01916	0.01595
	Q_{QC}	0.00122	0.00201	0.00265	0.00321	0.00376	0.00431	0.00453	0.00404	0.00356	0.00307	0.00259	0.00210	0.00160	0.00109
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00660	0.00965	0.01222	0.01479	0.01756	0.02066	0.02423	0.02844	0.03023	0.02825	0.02621	0.02404	0.02167	0.01899
	Q_{QC}	0.00097	0.00148	0.00188	0.00225	0.00261	0.00298	0.00336	0.00378	0.00381	0.00335	0.00290	0.00244	0.00199	0.00152
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 35 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04273	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00027	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05167	0.04235	0.03650	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00007	0.00061	0.00042	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-		-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.04971	0.04229	0.03724	0.03236	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00038	0.00102	0.00088	0.00050	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04826	0.04254	0.03818	0.03390	0.02958	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00081	0.00149	0.00139	0.00103	0.00055	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04733	0.04310	0.03932	0.03537	0.03128	0.027080	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00134	0.00203	0.00194	0.00159	0.00112	0.00058	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.04694	0.04396	0.04064	0.03695	0.03306	0.02902	0.02687	-	-	-	-	-	-
	Q_{QC}	-	0.00197	0.00262	0.00252	0.00218	0.00171	0.00118	0.00061	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.04713	0.04511	0.04212	0.03863	0.03488	0.03098	0.02697	0.02284	0.01003	-	-	-	-
	Q_{QC}	-	0.00268	0.00325	0.00314	0.00279	0.00232	0.00180	0.00123	0.00063	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 35 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.04663	0.04654	0.04374	0.04037	0.03674	0.03295	0.02906	0.02506	0.02094	0.00852	-	-	-
	Q_{QC}	-	0.00336	0.00394	0.00379	0.00342	0.00295	0.00242	0.00185	0.00126	0.00064	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.04901	0.03747	0.04819	0.04565	0.04214	0.03857	0.03489	0.03111	0.02724	0.02326	0.01914	0.00789	-	-
	Q_{QC}	0.00105	0.00327	0.00465	0.00446	0.00406	0.00358	0.00305	0.00268	0.00189	0.00128	0.00065	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	484.0	1107.7	-	-	-
500	Q_{QT}	0.03044	0.03111	0.04114	0.04718	0.04385	0.04034	0.03674	0.03307	0.02933	0.02551	0.02155	0.01742	0.00694	-
	Q_{QC}	0.00172	0.00316	0.00444	0.00514	0.00472	0.00422	0.00368	0.00311	0.00252	0.00192	0.00130	0.00066	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.4	137.9	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.01888	0.02617	0.03488	0.04361	0.04542	0.04194	0.03863	0.03489	0.03130	0.02765	0.02388	0.01995	0.01580	0.00492
	Q_{QC}	0.00168	0.00300	0.00415	0.00521	0.00537	0.00485	0.00430	0.00373	0.00314	0.00254	0.00193	0.00131	0.00066	-
	Queue	40.0	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.01408	0.02182	0.02887	0.03565	0.04267	0.04322	0.03983	0.03645	0.03307	0.02963	0.02610	0.02241	0.01851	0.01430
	Q_{QC}	0.00160	0.00276	0.00374	0.00463	0.00548	0.00545	0.00488	0.00431	0.00372	0.00314	0.00254	0.00193	0.0013	0.00067
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.01109	0.01730	0.02242	0.02729	0.03231	0.03779	0.04070	0.03758	0.03448	0.03136	0.02816	0.02482	0.02126	0.01738
	Q_{QC}	0.00145	0.00239	0.00315	0.00382	0.00448	0.00513	0.00539	0.00481	0.00423	0.00366	0.00308	0.00250	0.00190	0.00130
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00787	0.01159	0.01469	0.01774	0.02098	0.02456	0.02863	0.03339	0.03522	0.03264	0.03000	0.02724	0.02428	0.02099
	Q_{QC}	0.00115	0.00176	0.00224	0.00268	0.00311	0.00354	0.00400	0.00449	0.00453	0.00399	0.00345	0.00291	0.00236	0.00181
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 40 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04308	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00032	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05177	0.04315	0.03705	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00009	0.000073	0.00051	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.05022	0.04362	0.03840	0.03322	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00046	0.00123	0.00107	0.00060	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.04932	0.04450	0.04001	0.03525	0.03030	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00098	0.00180	0.00168	0.00124	0.00066	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.04909	0.04576	0.04186	0.03746	0.03275	0.02785	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00162	0.00265	0.00234	0.00192	0.00135	0.00070	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	426.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.04953	0.04739	0.04395	0.03981	0.03530	0.03057	0.02567	-	-	-	-	-	-
	Q_{QC}	-	0.00238	0.00316	0.00304	0.00263	0.00207	0.00163	0.00073	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.05065	0.04938	0.04625	0.04229	0.03793	0.03334	0.02858	0.02366	0.01003	-	-	-	-
	Q_{QC}	-	0.00323	0.00393	0.00379	0.00336	0.00280	0.00217	0.00148	0.00076	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 40 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.05083	0.05170	0.04871	0.04486	0.04060	0.03613	0.03149	0.02671	0.02178	0.00852	-	-	-
	Q_{QC}	-	0.00405	0.00475	0.00457	0.00412	0.00356	0.00292	0.00223	0.00152	0.00077	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	177.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.05039	0.04177	0.05430	0.05130	0.04747	0.04327	0.03889	0.03436	0.02972	0.02494	0.01999	0.00789	-	-
	Q_{QC}	0.00127	0.00395	0.00561	0.00537	0.00490	0.00432	0.00368	0.00299	0.00228	0.00155	0.00079	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	484.0	1107.7	-	-	-
500	Q_{QT}	0.03270	0.03526	0.04697	0.05392	0.05004	0.04587	0.04156	0.03715	0.03264	0.02802	0.02325	0.01829	0.00694	-
	Q_{QC}	0.00208	0.00381	0.00536	0.00620	0.00569	0.00509	0.00444	0.00375	0.00304	0.00231	0.00157	0.00079	-	-
	Queue	40.0	40.0	40.3	44.0	58.0	76.3	101.4	137.9	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.02107	0.03011	0.04032	0.05049	0.05246	0.04830	0.04406	0.03977	0.03542	0.03098	0.02641	0.02166	0.01667	0.00692
	Q_{QC}	0.00202	0.00362	0.00500	0.00628	0.00647	0.00585	0.00518	0.00449	0.00379	0.00307	0.00233	0.00158	0.00080	-
	Queue	40.0	40.0	40.[illegible]	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.01618	0.02544	0.03377	0.04172	0.04986	0.05037	0.04623	0.04211	0.03796	0.03375	0.02943	0.02494	0.02023	0.01517
	Q_{QC}	0.00192	0.00333	0.00451	0.00558	0.00661	0.00657	0.00589	0.00519	0.00449	0.00378	0.00306	0.00233	0.00158	0.00081
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.01300	0.02044	0.02655	0.03231	0.03819	0.04453	0.04776	0.04389	0.04004	0.03616	0.03220	0.02809	0.02375	0.01908
	Q_{QC}	0.00175	0.00289	0.00380	0.00461	0.00540	0.00619	0.00650	0.00580	0.00411	0.00441	0.00372	0.00301	0.00230	0.00156
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.00939	0.01390	0.01762	0.02125	0.02506	0.02921	0.03388	0.03928	0.04117	0.03788	0.03453	0.03106	0.02738	0.02337
	Q_{QC}	0.00139	0.00212	0.00270	0.00323	0.00375	0.00427	0.00483	0.00542	0.00547	0.00481	0.00416	0.00351	0.00285	0.00219
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 45 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	-	-	0.04350	0.01912	-	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	-	0.00039	-	-	-	-	-	-	-	-	-	-	-
	Queue	-	-	796.5	-	-	-	-	-	-	-	-	-	-	-
1300	Q_{QT}	-	0.05189	0.04410	0.03771	0.01828	-	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00011	0.00089	0.00062	-	-	-	-	-	-	-	-	-	-
	Queue	-	1901.4	347.2	670.4	-	-	-	-	-	-	-	-	-	-
1200	Q_{QT}	-	0.05081	0.04521	0.03978	0.03400	0.01609	-	-	-	-	-	-	-	-
	Q_{QC}	-	0.00057	0.00150	0.00130	0.00074	-	-	-	-	-	-	-	-	-
	Queue	-	367.9	205.7	314.7	698.6	-	-	-	-	-	-	-	-	-
1100	Q_{QT}	-	0.05059	0.04683	0.04218	0.03686	0.03116	0.01531	-	-	-	-	-	-	-
	Q_{QC}	-	0.00120	0.00220	0.00205	0.00152	0.00081	-	-	-	-	-	-	-	-
	Queue	-	173.2	139.0	197.4	333.4	757.5	-	-	-	-	-	-	-	-
1000	Q_{QT}	-	0.05119	0.04892	0.04489	0.03994	0.03450	0.02876	0.01306	-	-	-	-	-	-
	Q_{QC}	-	0.00198	0.00299	0.00286	0.00235	0.00165	0.00086	-	-	-	-	-	-	-
	Queue	-	103.9	101.2	139.4	211.9	362.9	826.6	-	-	-	-	-	-	-
900	Q_{QT}	-	0.05260	0.05147	0.04789	0.04321	0.03798	0.03242	0.02662	-	-	-	-	-	-
	Q_{QC}	-	0.00291	0.00386	0.00372	0.00321	0.00253	0.00174	0.00090	-	-	-	-	-	-
	Queue	-	70.2	77.3	105.0	151.1	231.0	395.2	899.1	-	-	-	-	-	-
800	Q_{QT}	-	0.05483	0.05446	0.05114	0.04664	0.04156	0.03614	0.03049	0.02464	0.01003	-	-	-	-
	Q_{QC}	-	0.00395	0.00480	0.00463	0.00411	0.00343	0.00265	0.00181	0.00092	-	-	-	-	-
	Queue	-	51.0	60.9	82.3	114.5	164.5	250.5	427.4	971.8	-	-	-	-	-

Table 9 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - SIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume - (assumed cruise speed is 45 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	-	0.05607	0.05784	0.05462	0.05019	0.04520	0.03990	0.03438	0.02867	0.02278	0.00852	-	-	-
	Q_{QC}	-	0.00495	0.00580	0.00558	0.00504	0.00434	0.00357	0.00273	0.00185	0.00094	-	-	-	-
	Queue	-	40.0	49.1	66.0	89.8	124.2	117.2	268.6	457.6	1042.1	-	-	-	-
600	Q_{QT}	0.05203	0.04687	0.06155	0.05825	0.05380	0.04886	0.04364	0.03824	0.03267	0.02694	0.02101	0.00789	-	-
	Q_{QC}	0.00155	0.00483	0.00686	0.00657	0.00599	0.00528	0.00449	0.00366	0.00279	0.00189	0.00096	-	-	-
	Queue	66.8	40.0	40.1	53.8	71.9	96.6	132.4	187.8	283.9	486.0	1107.7	-	-	-
500	Q_{QT}	0.03539	0.04019	0.05390	0.06194	0.05760	0.05245	0.04730	0.04200	0.03658	0.03101	0.02527	0.01931	0.00694	-
	Q_{QC}	0.00254	0.00466	0.00655	0.00758	0.00695	0.00622	0.00542	0.00458	0.00372	0.00283	0.00191	0.00097	-	-
	Queue	40.0	40.0	40.0	44.0	58.0	76.3	101.4	137.9	195.0	294.7	504.4	1164.9	-	-
400	Q_{QT}	0.02369	0.03479	3.04679	0.05857	0.06083	0.05586	0.05076	0.04558	0.04032	0.03495	0.02943	0.02370	0.01771	0.00492
	Q_{QC}	0.00247	0.00442	0.00611	0.00768	0.00791	0.00714	0.00633	0.00549	0.00463	0.00375	0.00285	0.00193	0.00092	-
	Queue	40.0	40.0	40.0	40.0	46.5	60.2	78.2	103.1	139.5	197.1	298.8	515.5	1208.3	-
300	Q_{QT}	0.01866	0.02975	).03960	0.04893	0.05841	0.05886	0.05384	0.04882	0.04376	0.03864	0.03339	0.02796	0.02227	0.01622
	Q_{QC}	0.00235	0.00407	0.00551	0.00682	0.00808	0.00803	0.00719	0.00635	0.00549	0.00462	0.00374	0.00285	0.00193	0.00098
	Queue	40.0	40.0	40.0	40.0	40.0	46.6	59.4	76.5	100.4	135.6	191.8	292.6	511.1	1226.4
200	Q_{QT}	0.01526	0.02417	0.03146	0.03827	0.04516	0.05254	0.05616	0.05139	0.04664	0.04187	0.03700	0.03199	0.02673	0.02110
	Q_{QC}	0.00214	0.00353	0.00464	0.00564	0.00660	0.00757	0.00794	0.00709	0.00624	0.00539	0.00454	0.00368	0.0028	0.00191
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	43.3	54.7	70.0	91.5	123.5	175.3	269.6	479.5
100	Q_{QT}	0.01119	0.01664	0.02111	0.02543	0.02990	0.03474	0.04012	0.04629	0.04824	0.04409	0.03990	0.03559	0.03107	0.02620
	Q_{QC}	0.00170	0.00259	0.00330	0.00395	0.00458	0.00522	0.00590	0.00662	0.00668	0.00588	0.00588	0.00628	0.00348	0.00267
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	44.4	56.6	73.7	99.2	140.7	217.3

Table 10. FREE FLOW EMISSION RATE Q_f, IN GRAMS PER METER-SECOND AS A FUNCTION OF LANE VOLUME AND VEHICLE SPEED ON ROADWAYS.

Cruise speed (mi/hr)	Traffic volume for lane (vehicles per hour)													
	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
15	0.00086	0.00171	0.00257	0.00342	0.00428	0.00514	0.00599	0.00685	0.00770	0.00856	0.00942	0.01027	0.01113	0.01198
20	0.00059	0.00119	0.00178	0.00237	0.00296	0.00356	0.00415	0.00474	0.00533	0.00593	0.00652	0.00711	0.00770	0.00830
25	0.00045	0.00090	0.00135	0.00180	0.00225	0.00270	0.00315	0.00361	0.00406	0.00451	0.00496	0.00541	0.00586	0.00631
30	0.00037	0.00074	0.00111	0.00148	0.00185	0.00222	0.00259	0.00296	0.00333	0.00370	0.00406	0.00443	0.00480	0.00517
35	0.00032	0.00065	0.00097	0.00129	0.00162	0.00194	0.00226	0.00258	0.00291	0.00323	0.00355	0.00388	0.00420	0.00452
40	0.00030	0.00060	0.00090	0.00119	0.00149	0.00179	0.00209	0.00239	0.00269	0.00298	0.00328	0.00358	0.00388	0.00418
45	0.00029	0.00058	0.00086	0.00115	0.00144	0.00173	0.00202	0.00230	0.00259	0.00288	0.00317	0.00346	0.00374	0.00403

Table 11. TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 15 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.02945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.01604	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01056	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.00777	0.05160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00039	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.00619	0.04640	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.00522	0.02456	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.00460	0.01662	0.05237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00109	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.1033	0.01119	0.01205
	Queue	40.0	40.0	94.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 15 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.00419	0.01276	0.04331	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.00391	0.01059	0.02647	0.05351	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00127	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.00372	0.00928	0.01959	0.05036	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.00358	0.00844	0.01605	0.03164	0.05622	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00252	0.00517	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.00348	0.00787	0.01399	0.02405	0.04697	0.05494	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00142	0.00603	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.00341	0.00748	0.01269	0.02016	0.03293	0.06221	0.05369	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00494	0.00064	0.00689	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	41.8	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.00336	0.00720	0.01184	0.01785	0.02659	0.04208	0.06211	0.05278	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00086	0.00172	0.00258	0.00344	0.00430	0.00517	0.00446	0.00016	0.00775	0.00861	0.00947	0.01033	0.01119	0.01205
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	54.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 20 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.03066	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.01725	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01177	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.00898	0.05215	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00068	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.00739	0.04882	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.00643	0.02698	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.00581	0.01904	0.05391	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00135	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	96.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 20 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.00540	0.01517	0.04693	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.00512	0.01301	0.03010	0.05530	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00157	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.00493	0.01170	0.02322	0.05520	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.00479	0.01085	0.01968	0.03647	0.05975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00310	0.00636	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.00469	0.01029	0.01761	0.02889	0.05301	0.05696	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00175	0.00742	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.00462	0.00990	0.01632	0.02497	0.03898	0.06915	0.05659	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00608	0.00078	0.00848	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	41.8	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.00456	0.00962	0.01547	0.02269	0.03264	0.04934	0.06838	0.05301	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00106	0.00212	0.00318	0.00424	0.00530	0.00636	0.00549	0.00020	0.00954	0.01060	0.01166	0.01272	0.01377	0.01483
	Queue	40.0	40.0	40.0	40.0	40.0	41.8		1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 25 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.03205	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.01864	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01316	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.01037	0.05278	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00057	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.00879	0.05160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.00782	0.02976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.0511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.00720	0.02182	0.05568	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00160	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	94.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 25 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.00679	0.01796	0.05111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.00651	0.01580	0.03427	0.05736	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00186	0.00630	0.00756	0.00881	0.01007	0.01133	0.01239	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.0632	0.01446	0.02740	0.06076	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.00618	0.01364	0.02385	0.04204	0.06382	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00368	0.00756	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.00608	0.01307	0.02179	0.03445	0.05997	0.05924	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00208	0.00881	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.00601	0.01268	0.02050	0.03054	0.04593	0.07713	0.05561	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00723	0.00093	0.01007	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.0	40.0	40.0	40.0	41.8	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.00396	0.01241	0.01964	0.02825	0.03960	0.05769	0.07559	0.05326	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00126	0.00252	0.00378	0.00504	0.00630	0.00756	0.00653	0.00023	0.01133	0.01259	0.01385	0.01511	0.01637	0.01763
	Queue	40.0	40.C	40.0	40.0	40.0	40.0	54.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 30 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.03369	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.02028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01480	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.01201	0.05352	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00067	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.01042	0.05488	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.00946	0.03304	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.0282
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.00884	0.02510	0.05776	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00189	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 30 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.00843	0.02123	0.05602	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.00815	0.01907	0.03919	0.05977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00496	0.00220	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.00796	0.01776	0.03231	0.06732	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.00782	0.01691	0.02876	0.04859	0.06861	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00635	0.00892	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.00772	0.01635	0.02670	0.04101	0.06816	0.06195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00246	0.01041	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.00765	0.01596	0.02541	0.03709	0.05412	0.08653	0.05682	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00853	0.00110	0.01189	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	41.8	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.00759	0.01568	0.02456	0.03481	0.04778	0.06751	0.08408	0.05357	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00149	0.00297	0.00446	0.00595	0.00743	0.00892	0.00771	0.00028	0.01338	0.01487	0.01635	0.01784	0.01933	0.02082
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	54.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (QQC), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 35 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.03564	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.02223	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01674	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.01396	0.05640	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00880	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.01127	0.05877	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.01140	0.03693	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.01079	0.02899	0.06023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00225	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	96.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 35 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.01038	0.02513	0.06187	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.01010	0.02297	0.04503	0.06265	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00261	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.00990	0.02165	0.03815	0.07511	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.00977	0.02081	0.03461	0.05638	0.07431	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00517	0.01062	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.00967	0.02024	0.03254	0.04880	0.07790	0.06518	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.00293	0.01239	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.00959	0.01985	0.03125	0.4488	0.6386	0.09771	0.05826	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01015	0.00131	0.01415	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.00954	0.01958	0.03040	0.04260	0.05752	0.007920	0.09418	0.05393	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00177	0.00354	0.00531	0.00708	0.00885	0.01062	0.00917	0.00033	0.01592	0.01769	0.01946	0.02123	0.02300	0.02477
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	54.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 40 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.03796	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.0640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.02455	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.01907	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.01628	0.05545	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00096	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.2134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.01469	0.06342	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.01373	0.04157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.01311	0.03363	0.06318	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00271	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	94.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 40 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.01270	0.02977	0.06883	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.0.2347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.01242	0.02761	0.05200	0.06608	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00315	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.01222	0.02630	0.04512	0.08439	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.01209	0.02565	0.04157	0.06567	0.08110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QT}	0.00213	0.00427	0.00640	0.00854	0.00624	0.01280	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	68.6	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.01199	0.02489	0.03951	0.05808	0.08951	0.06902	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.00353	0.01494	0.01707	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.01192	0.02450	0.03951	0.05417	0.07547	0.11103	0.05998	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01225	0.00158	0.01707	0.01921	0.02134	0.02347	0.02561	0.01773	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.01186	0.02422	0.03736	0.05188	0.06913	0.09313	0.10622	0.05436	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00213	0.00427	0.00640	0.00854	0.01067	0.01280	0.01106	0.0039	0.01921	0.02134	0.02347	0.02561	0.02774	0.02988
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	54.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicles/hour) cruise speed is 45 mi/hr)													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1400	Q_{QT}	0.04072	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01826	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1300	Q_{QT}	0.02731	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1200	Q_{QT}	0.02182	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1100	Q_{QT}	0.01904	0.05670	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00118	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	176.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1000	Q_{QT}	0.01745	0.06894	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
900	Q_{QT}	0.01649	0.04709	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
800	Q_{QT}	0.01587	0.03915	0.06669	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00331	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	96.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 11 (continued). TOTAL QUEUE EMISSIONS, (Q_{QT}), CRUISE COMPONENT EMISSION, (Q_{QC}), AND QUEUE LENGTH AS A FUNCTION OF MAJOR AND CROSS-STREET VOLUMES AND CRUISE SPEED - UNSIGNALIZED INTERSECTIONS

Cross-street effective lane volume (veh/hr)	Element	Major street volume (vehicle/hour) cruise speed is 45 mi/hr													
		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
700	Q_{QT}	0.01546	0.03529	0.07711	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
600	Q_{QT}	0.01518	0.03313	0.06027	0.07016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.00985	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	108.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
500	Q_{QT}	0.01498	0.03181	0.05339	0.09543	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
400	Q_{QT}	0.01485	0.03097	0.04985	0.07670	0.08917	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.00763	0.01565	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	68.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
300	Q_{QT}	0.01475	0.03040	0.04779	0.06912	0.10330	0.07358	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00761	0.00522	0.00782	0.01043	0.01304	0.00431	0.01825	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	145.1	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
200	Q_{QT}	0.01468	0.03001	0.04649	0.06521	0.08926	0.12686	0.06201	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01496	0.00193	0.02086	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	41.8	379.3	40.0	40.0	40.0	40.0	40.0	40.0	40.0
100	Q_{QT}	0.01462	0.02974	0.04564	0.06292	0.08293	0.10968	0.12053	0.05487	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{QC}	0.00261	0.00522	0.00782	0.01043	0.01304	0.01565	0.01352	0.00048	0.02347	0.02608	0.02868	0.03129	0.03390	0.03651
	Queue	40.0	40.0	40.0	40.0	40.0	40.0	56.0	1729.4	40.0	40.0	40.0	40.0	40.0	40.0

Table 12. EMISSION CORRECTION FACTORS FOR REGION, CALENDAR YEAR, SPEED, PERCENT COLD STARTS (C) PERCENT HOT STARTS (H) AND TEMPERATURE (T) BY VEHICLE TYPE (M)

EMISSION CORRECTION FACTORS FOR REGION: LOW ALTITUDE

			YEAR:	1978	1978	1978	1978	1980	1980	1980	1980	1982	1982	1982	1982	1985	1985	1985	1985	1987	1987	1987	1987	1990	1990	1990	1990
			SPEED	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45
M	H	C	T																								
LDV	20	10	20	1.22	1.30	1.37	1.42	1.00	1.11	1.17	1.22	0.74	0.83	0.89	0.93	0.47	0.52	0.57	0.60	0.38	0.40	0.44	0.46	0.31	0.30	0.33	0.35
	20	10	40	1.12	1.18	1.23	1.26	0.91	0.99	1.04	1.08	0.67	0.75	0.79	0.82	0.43	0.47	0.51	0.54	0.35	0.37	0.40	0.42	0.29	0.28	0.31	0.32
	20	35	20	1.94	2.17	2.39	2.58	1.64	1.88	2.09	2.25	1.25	1.43	1.59	1.72	0.85	0.92	1.04	1.13	0.71	0.72	0.81	0.88	0.61	0.57	0.64	0.69
	20	35	40	1.57	1.74	1.90	2.03	1.31	1.49	1.63	1.75	1.00	1.13	1.25	1.35	0.69	0.75	0.84	0.90	0.59	0.60	0.67	0.73	0.52	0.49	0.55	0.60
	20	60	20	2.65	3.03	3.42	3.74	2.28	2.66	3.00	3.29	1.75	2.03	2.29	2.51	1.22	1.33	1.50	1.65	1.03	1.06	1.19	1.30	0.90	0.83	0.94	1.04
	20	60	40	2.03	2.30	2.57	2.81	1.72	1.98	2.23	2.43	1.33	1.52	1.71	1.87	0.96	1.03	1.16	1.27	0.84	0.84	0.95	1.04	0.75	0.70	0.79	0.87
	40	10	20	1.24	1.32	1.39	1.44	1.02	1.12	1.19	1.24	0.75	0.85	0.90	0.95	0.49	0.54	0.58	0.61	0.39	0.41	0.45	0.48	0.33	0.32	0.35	0.37
	40	10	40	1.14	1.20	1.25	1.28	0.92	1.01	1.06	1.09	0.68	0.76	0.81	0.84	0.44	0.49	0.53	0.55	0.36	0.38	0.41	0.43	0.30	0.29	0.32	0.34
	40	35	20	1.96	2.19	2.41	2.60	1.66	1.90	2.10	2.27	1.26	1.44	1.61	1.73	0.86	0.94	1.05	1.14	0.72	0.74	0.83	0.90	0.62	0.58	0.65	0.71
	40	35	40	1.60	1.76	1.92	2.05	1.33	1.50	1.65	1.77	1.01	1.15	1.27	1.36	0.71	0.76	0.85	0.92	0.61	0.62	0.69	0.74	0.54	0.50	0.56	0.61
	40	60	20	2.67	3.05	3.44	3.76	2.30	2.68	3.02	3.30	1.76	2.04	2.31	2.52	1.23	1.34	1.52	1.66	1.05	1.06	1.20	1.32	0.91	0.84	0.96	1.05
	40	60	40	2.05	2.32	2.60	2.83	1.73	2.00	2.24	2.44	1.34	1.53	1.73	1.88	0.97	1.04	1.18	1.28	0.85	0.85	0.97	1.06	0.77	0.71	0.81	0.88
LDT	20	10	20	3.16	3.17	3.35	3.51	2.86	3.00	3.19	3.34	2.50	2.83	3.04	3.19	0.97	1.18	1.27	1.34	1.53	1.99	2.15	2.26	0.52	0.76	0.83	0.87
	20	10	40	2.94	2.91	3.06	3.18	2.65	2.74	2.89	3.01	2.30	2.56	2.72	2.88	0.88	1.06	1.14	1.19	1.40	1.79	1.91	2.00	0.47	0.68	0.74	0.77
	20	35	20	4.80	5.11	5.65	6.10	4.38	4.92	5.45	5.90	3.94	4.76	5.30	5.75	1.55	2.00	2.23	2.42	2.44	3.36	3.76	4.07	0.83	1.30	1.46	1.58
	20	35	40	4.03	4.22	4.62	4.97	3.65	4.00	4.40	4.73	3.23	3.79	4.19	4.52	1.26	1.58	1.75	1.89	1.99	2.65	2.95	3.17	0.67	1.02	1.14	1.23
	20	60	20	6.43	7.05	7.95	8.70	5.91	6.84	7.72	8.46	5.37	6.69	7.57	8.30	2.13	2.81	3.18	3.49	3.36	4.74	5.36	5.88	1.15	1.84	2.09	2.29
	20	60	40	5.11	5.52	6.19	6.76	4.66	5.26	5.91	6.45	4.16	5.03	5.66	6.19	1.63	2.10	2.36	2.58	2.58	3.52	3.98	4.35	0.88	1.36	1.54	1.68
	40	10	20	3.21	3.22	3.40	3.55	2.90	3.04	3.23	3.39	2.54	2.87	3.08	3.23	0.98	1.20	1.29	1.36	1.55	2.01	2.17	2.28	0.52	0.77	0.84	0.88
	40	10	40	2.99	2.96	3.10	3.23	2.69	2.78	2.93	3.05	2.33	2.59	2.76	2.88	0.90	1.08	1.15	1.20	1.42	1.81	1.94	2.03	0.48	0.69	0.75	0.78
	40	35	20	4.84	5.16	5.69	6.15	4.42	4.96	5.49	5.94	3.97	4.80	5.34	5.79	1.56	2.01	2.24	2.43	2.47	3.39	3.78	4.10	0.84	1.31	1.47	1.59
	40	35	40	4.08	4.26	4.67	5.02	3.70	4.04	4.44	4.77	3.26	3.83	4.23	4.56	1.27	1.59	1.77	1.90	2.01	2.68	2.97	3.20	0.68	1.03	1.15	1.24
	40	60	20	6.47	7.10	7.99	8.75	5.95	6.88	7.76	8.50	5.41	6.73	7.61	8.34	2.14	2.83	3.20	3.51	3.38	4.76	5.39	5.91	1.15	1.85	2.10	2.30
	40	60	40	5.16	5.56	6.24	6.80	4.70	5.30	5.95	6.50	4.19	5.07	5.70	6.23	1.64	2.11	2.38	2.60	2.60	3.55	4.00	4.37	0.88	1.37	1.55	1.69
MC	20	10	20	0.47	0.81	0.92	1.02	0.38	0.67	0.72	0.77	0.30	0.54	0.57	0.60	0.15	0.27	0.28	0.29	0.09	0.18	0.18	0.19	0.07	0.12	0.13	0.13
	20	10	40	0.42	0.73	0.83	0.92	0.34	0.59	0.64	0.68	0.27	0.48	0.50	0.52	0.13	0.24	0.25	0.25	0.08	0.15	0.16	0.16	0.06	0.11	0.11	0.11
	20	35	20	0.78	1.36	1.55	1.71	0.63	1.17	1.31	1.43	0.51	0.98	1.08	1.17	0.25	0.49	0.54	0.58	0.16	0.32	0.35	0.38	0.11	0.23	0.25	0.27
	20	35	40	0.62	1.08	1.23	1.35	0.50	0.91	1.01	1.10	0.40	0.75	0.82	0.89	0.20	0.38	0.41	0.44	0.13	0.24	0.26	0.28	0.09	0.17	0.19	0.20
	20	60	20	1.09	1.90	2.17	2.40	0.89	1.68	1.90	2.09	0.72	1.41	1.60	1.75	0.36	0.71	0.80	0.87	0.23	0.46	0.52	0.57	0.16	0.33	0.37	0.41
	20	60	40	0.81	1.42	1.62	1.79	0.66	1.23	1.39	1.52	0.53	1.02	1.15	1.26	0.26	0.51	0.57	0.63	0.17	0.33	0.37	0.41	0.12	0.24	0.27	0.29
	40	10	20	0.47	0.82	0.93	1.03	0.38	0.68	0.73	0.78	0.30	0.55	0.58	0.61	0.15	0.28	0.29	0.30	0.10	0.18	0.18	0.19	0.07	0.13	0.13	0.13
	40	10	40	0.43	0.74	0.84	0.92	0.34	0.60	0.65	0.69	0.27	0.49	0.51	0.53	0.14	0.24	0.25	0.26	0.09	0.16	0.16	0.16	0.06	0.11	0.11	0.11
	40	35	20	0.78	1.36	1.56	1.72	0.64	1.18	1.32	1.44	0.52	0.99	1.09	1.18	0.26	0.49	0.54	0.59	0.16	0.32	0.35	0.38	0.11	0.23	0.25	0.27
	40	35	40	0.62	1.08	1.24	1.36	0.50	0.92	1.02	1.11	0.40	0.76	0.83	0.89	0.20	0.38	0.41	0.44	0.13	0.25	0.27	0.29	0.09	0.18	0.19	0.20
	40	60	20	1.09	1.91	2.18	2.41	0.90	1.69	1.91	2.10	0.73	1.42	1.60	1.76	0.36	0.71	0.80	0.88	0.23	0.46	0.52	0.57	0.16	0.34	0.38	0.41
	40	60	40	0.82	1.43	1.63	1.80	0.66	1.24	1.39	1.53	0.53	1.03	1.16	1.26	0.26	0.52	0.58	0.63	0.17	0.34	0.38	0.41	0.12	0.24	0.27	0.29
HDG				1.72	5.80	5.51	6.36	1.73	5.54	5.62	6.56	1.73	5.23	5.77	6.91	1.57	3.97	4.67	5.68	1.52	3.21	3.91	4.78	1.55	2.52	3.20	3.95
HDD				0.83	0.62	0.60	0.62	0.83	0.60	0.57	0.57	0.83	0.60	0.55	0.53	0.83	0.59	0.53	0.51	0.83	0.59	0.52	0.51	0.83	0.59	0.52	0.50

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Table 12 (continued). EMISSION CORRECTION FACTORS FOR REGION, CALENDAR YEAR, SPEED, PERCENT COLD STARTS (C) PERCENT HOT STARTS (H) AND TEMPERATURE (T) BY VEHICLE TYPE (M)

EMISSION CORRECTION FACTORS FOR REGION: HIGH ALTITUDE

			YEAR:	1978	1978	1978	1978	1980	1980	1980	1980	1982	1982	1982	1982	1985	1985	1985	1985	1987	1987	1987	1987	1990	1990	1990	1990
			SPEED:	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45
M	H	C	T																								
LDV	20	10	20	1.04	1.73	2.13	2.44	0.85	1.46	1.76	1.98	0.65	1.07	1.26	1.40	0.45	0.64	0.73	0.80	0.37	0.46	0.52	0.57	0.31	0.32	0.36	0.39
	20	10	40	0.93	1.56	1.93	2.22	0.76	1.30	1.58	1.78	0.58	0.96	1.13	1.26	0.40	0.58	0.66	0.72	0.34	0.42	0.48	0.51	0.29	0.30	0.33	0.36
	20	35	20	1.84	2.94	3.48	3.91	1.53	2.56	2.99	3.33	1.19	1.87	2.17	2.40	0.84	1.13	1.29	1.42	0.71	0.83	0.95	1.04	0.61	0.60	0.68	0.75
	20	35	40	1.48	2.34	2.79	3.14	1.21	2.00	2.35	2.62	0.94	1.47	1.71	1.90	0.68	0.91	1.04	1.15	0.59	0.69	0.79	0.86	0.52	0.52	0.59	0.64
	20	60	20	2.65	4.16	4.83	5.38	2.22	3.65	4.22	4.68	1.73	2.67	3.07	3.40	1.22	1.62	1.86	2.05	1.04	1.20	1.38	1.52	0.90	0.88	1.00	1.10
	20	60	40	2.02	3.13	3.65	4.07	1.66	2.69	3.11	3.46	1.30	1.99	2.29	2.54	0.96	1.25	1.43	1.57	0.85	0.96	1.10	1.21	0.76	0.74	0.84	0.92
	40	10	20	1.03	1.71	2.11	2.41	0.85	1.46	1.75	1.97	0.65	1.07	1.26	1.40	0.46	0.65	0.74	0.81	0.38	0.47	0.54	0.58	0.32	0.33	0.37	0.40
	40	10	40	0.92	1.54	1.91	2.19	0.75	1.30	1.57	1.76	0.58	0.96	1.13	1.26	0.41	0.58	0.67	0.73	0.35	0.43	0.49	0.53	0.30	0.31	0.35	0.37
	40	35	20	1.83	2.93	3.46	3.88	1.53	2.55	2.98	3.32	1.19	1.87	2.17	2.40	0.84	1.14	1.30	1.43	0.72	0.84	0.96	1.05	0.62	0.61	0.70	0.76
	40	35	40	1.47	2.33	2.77	3.12	1.20	1.99	2.34	2.60	0.94	1.47	1.71	1.89	0.69	0.92	1.05	1.16	0.61	0.70	0.80	0.87	0.54	0.53	0.60	0.65
	40	60	20	2.64	4.14	4.81	5.35	2.21	3.65	4.21	4.67	1.73	2.67	3.07	3.40	1.23	1.63	1.87	2.06	1.06	1.22	1.39	1.53	0.92	0.89	1.02	1.12
	40	60	40	2.01	3.11	3.63	4.04	1.66	2.68	3.10	3.44	1.31	1.99	2.29	2.53	0.97	1.26	1.44	1.58	0.86	0.97	1.11	1.22	0.78	0.75	0.85	0.94
LDT	20	10	20	3.93	4.40	5.54	6.42	3.43	4.04	5.00	5.74	2.88	3.74	4.53	5.12	1.06	1.46	1.73	1.92	1.63	2.33	2.74	3.03	0.54	0.85	0.98	1.08
	20	10	40	3.57	4.02	5.11	5.94	3.12	3.66	4.57	5.26	2.60	3.35	4.08	4.62	0.96	1.30	1.55	1.73	1.48	2.09	2.46	2.73	0.49	0.76	0.88	0.96
	20	35	20	6.77	7.28	8.69	9.82	5.86	6.78	8.04	9.03	4.95	6.42	7.53	8.41	1.81	2.49	2.90	3.21	2.77	3.97	4.60	5.09	0.91	1.45	1.67	1.84
	20	35	40	5.51	5.95	7.17	8.14	4.77	5.46	6.52	7.36	3.99	5.06	5.97	6.68	1.46	1.96	2.29	2.58	2.24	3.13	3.64	4.03	0.74	1.13	1.31	1.44
	20	60	20	9.62	10.16	11.85	13.23	8.29	9.52	11.07	12.33	7.03	9.11	10.53	11.70	2.57	3.53	4.07	4.50	3.91	5.61	6.46	7.14	1.29	2.05	2.35	2.59
	20	60	40	7.45	7.88	9.24	10.35	6.43	7.26	8.48	9.47	5.38	6.78	7.86	8.74	1.96	2.62	3.03	3.35	3.00	4.17	4.81	5.32	0.99	1.51	1.74	1.92
	40	10	20	3.88	4.35	5.46	6.32	3.38	4.00	4.95	5.67	2.85	3.72	4.49	5.07	1.05	1.45	1.72	1.92	1.62	2.33	2.73	3.02	0.54	0.85	0.98	1.08
	40	10	40	3.52	3.97	5.03	5.84	3.07	3.62	4.51	5.19	2.58	3.33	4.05	4.58	0.95	1.30	1.55	1.72	1.47	2.09	2.46	2.72	0.49	0.76	0.88	0.96
	40	35	20	6.72	7.22	8.62	9.73	5.82	6.74	7.98	8.96	4.93	6.40	7.50	8.37	1.81	2.49	2.89	3.21	2.76	3.97	4.59	5.08	0.91	1.45	1.67	1.83
	40	35	40	5.46	5.90	7.10	8.05	4.73	5.42	6.47	7.29	3.97	5.04	5.94	6.64	1.45	1.96	2.28	2.53	2.23	3.13	3.63	4.02	0.74	1.14	1.31	1.44
	40	60	20	9.56	10.10	11.77	13.13	8.25	9.48	11.01	12.26	7.00	9.09	10.50	11.66	2.56	3.53	4.06	4.49	3.90	5.61	6.45	7.14	1.29	2.05	2.35	2.59
	40	60	40	7.40	7.82	9.16	10.25	6.38	7.22	8.42	9.40	5.35	6.75	7.83	8.70	1.95	2.62	3.02	3.34	2.99	4.17	4.80	5.31	0.98	1.51	1.74	1.92
MC	20	10	20	1.45	1.09	1.39	1.63	0.88	0.88	1.12	1.32	0.58	0.70	0.90	1.05	0.26	0.34	0.44	0.52	0.14	0.20	0.26	0.30	0.08	0.13	0.16	0.19
	20	10	40	1.28	0.98	1.26	1.50	0.77	0.78	1.01	1.19	0.50	0.62	0.80	0.94	0.23	0.30	0.39	0.46	0.12	0.18	0.23	0.27	0.07	0.11	0.14	0.17
	20	35	20	2.67	1.84	2.21	2.52	1.66	1.57	1.89	2.14	1.12	1.30	1.55	1.76	0.50	0.63	0.76	0.86	0.27	0.37	0.45	0.51	0.16	0.24	0.29	0.33
	20	35	40	2.08	1.45	1.77	2.03	1.28	1.21	1.47	1.69	0.85	0.99	1.20	1.37	0.38	0.48	0.59	0.67	0.21	0.28	0.35	0.39	0.12	0.18	0.22	0.25
	20	60	20	3.90	2.59	3.03	3.40	2.44	2.27	2.65	2.96	1.66	1.89	2.21	2.47	0.75	0.92	1.08	1.20	0.41	0.55	0.64	0.71	0.24	0.35	0.41	0.46
	20	60	40	2.88	1.93	2.27	2.56	1.79	1.65	1.94	2.18	1.20	1.36	1.60	1.79	0.54	0.67	0.78	0.88	0.29	0.39	0.46	0.52	0.17	0.25	0.30	0.33
	40	10	20	1.43	1.08	1.38	1.62	0.87	0.87	1.11	1.30	0.57	0.69	0.89	1.04	0.26	0.34	0.43	0.51	0.14	0.20	0.25	0.30	0.08	0.13	0.16	0.19
	40	10	40	1.27	0.97	1.25	1.48	0.76	0.77	0.99	1.17	0.50	0.61	0.78	0.93	0.22	0.30	0.38	0.45	0.12	0.17	0.22	0.26	0.07	0.11	0.14	0.17
	40	35	20	2.66	1.83	2.20	2.50	1.65	1.56	1.87	2.12	1.11	1.29	1.54	1.74	0.50	0.63	0.75	0.85	0.27	0.37	0.44	0.50	0.16	0.24	0.29	0.32
	40	35	40	2.07	1.44	1.76	2.01	1.27	1.20	1.46	1.67	0.84	0.98	1.19	1.35	0.38	0.48	0.58	0.66	0.21	0.28	0.34	0.39	0.12	0.18	0.22	0.25
	40	60	20	3.88	2.58	3.02	3.38	2.44	2.26	2.64	2.95	1.65	1.88	2.19	2.45	0.74	0.92	1.07	1.20	0.41	0.54	0.63	0.71	0.24	0.35	0.41	0.46
	40	60	40	2.87	1.92	2.26	2.54	1.78	1.64	1.93	2.16	1.19	1.35	1.59	1.78	0.54	0.66	0.78	0.87	0.29	0.39	0.46	0.51	0.17	0.25	0.30	0.33
HDG				2.36	8.61	8.19	9.48	2.29	8.13	8.29	9.70	2.18	7.61	8.46	10.15	1.83	5.52	6.51	7.93	1.69	4.22	5.11	6.25	1.62	3.02	3.79	4.66
HDD				0.88	1.01	0.97	1.00	0.88	0.98	0.92	0.92	0.87	0.97	0.88	0.87	0.86	0.86	0.77	0.74	0.84	0.78	0.66	0.63	0.83	0.65	0.57	0.55

Table 12 (continued). EMISSION CORRECTION FACTORS FOR REGION, CALENDAR YEAR, SPEED, PERCENT COLD STARTS (C) PERCENT HOT STARTS (H) AND TEMPERATURE (T) BY VEHICLE TYPE (M)

EMISSION CORRECTION FACTORS FOR REGION: CALIFORNIA

			YEAR:	1978	1978	1978	1978	1980	1980	1980	1980	1982	1982	1982	1982	1985	1985	1985	1985	1987	1987	1987	1987	1990	1990	1990	1990
			SPEED:	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45	0	15	30	45
M	H	C	T																								
LDV	20	10	20	1.00	1.07	1.11	1.14	0.74	0.81	0.85	0.87	0.44	0.60	0.63	0.66	0.18	0.40	0.44	0.46	0.11	0.35	0.38	0.40	0.06	0.31	0.34	0.36
	20	10	40	1.02	1.00	1.02	1.04	0.69	0.76	0.79	0.80	0.41	0.56	0.59	0.61	0.17	0.38	0.41	0.43	0.10	0.32	0.35	0.37	0.06	0.29	0.32	0.33
	20	35	20	1.44	1.71	1.87	2.01	1.10	1.33	1.46	1.57	0.66	1.01	1.12	1.21	0.28	0.73	0.82	0.89	0.17	0.65	0.73	0.79	0.11	0.59	0.67	0.73
	20	35	40	1.41	1.65	1.58	1.68	0.96	1.14	1.25	1.33	0.58	0.88	0.97	1.04	0.24	0.64	0.72	0.78	0.15	0.57	0.64	0.69	0.10	0.52	0.58	0.63
	20	60	20	2.19	2.35	2.64	2.87	1.47	1.84	2.07	2.26	0.80	1.43	1.61	1.76	0.38	1.06	1.21	1.32	0.24	0.95	1.08	1.19	0.16	0.87	0.99	1.09
	20	60	40	1.79	1.91	2.14	2.32	1.22	1.52	1.71	1.86	0.70	1.20	1.35	1.47	0.32	0.91	1.03	1.12	0.20	0.81	0.92	1.01	0.13	0.75	0.85	0.93
	40	10	20	1.11	1.09	1.13	1.16	0.75	0.83	0.87	0.89	0.45	0.62	0.65	0.67	0.18	0.42	0.46	0.48	0.11	0.36	0.40	0.42	0.06	0.32	0.36	0.38
	40	10	40	1.04	1.02	1.05	1.06	0.71	0.78	0.81	0.82	0.42	0.58	0.61	0.63	0.17	0.40	0.43	0.45	0.10	0.34	0.37	0.39	0.06	0.30	0.33	0.35
	40	35	20	1.46	1.73	1.89	2.03	1.12	1.35	1.48	1.59	0.67	1.03	1.14	1.23	0.28	0.75	0.84	0.91	0.18	0.67	0.75	0.81	0.11	0.61	0.68	0.70
	40	35	40	1.43	1.48	1.60	1.70	0.97	1.16	1.27	1.35	0.58	0.90	0.99	1.06	0.25	0.66	0.74	0.79	0.15	0.59	0.66	0.71	0.10	0.53	0.60	0.65
	40	60	20	2.21	2.37	2.66	2.90	1.48	1.86	2.09	2.28	0.89	1.45	1.63	1.78	0.38	1.08	1.22	1.34	0.24	0.97	1.10	1.21	0.16	0.89	1.01	1.11
	40	60	40	1.81	1.93	2.16	2.34	1.23	1.55	1.73	1.88	0.75	1.22	1.37	1.49	0.32	0.92	1.05	1.14	0.21	0.83	0.94	1.03	0.14	0.76	0.87	0.95
LDT	20	10	20	3.23	3.05	3.10	3.12	2.81	2.69	2.76	2.79	2.32	2.27	2.34	2.38	0.81	0.85	0.88	0.90	1.27	1.40	1.47	1.51	0.45	0.55	0.59	0.61
	20	10	40	3.02	2.84	2.85	2.84	2.64	2.51	2.55	2.56	2.10	2.13	2.18	2.20	0.77	0.80	0.83	0.84	1.21	1.32	1.38	1.41	0.43	0.52	0.55	0.57
	20	35	20	5.05	4.92	5.34	5.68	4.46	4.40	4.80	5.11	3.71	3.75	4.10	4.38	1.32	1.42	1.57	1.68	2.09	2.40	2.65	2.84	0.77	0.97	1.08	1.17
	20	35	40	4.29	4.16	4.48	4.73	3.83	3.77	4.08	4.32	3.23	3.25	3.54	3.76	1.16	1.25	1.37	1.46	1.86	2.12	2.33	2.48	0.69	0.86	0.95	1.03
	20	60	20	6.87	6.70	7.59	8.25	6.10	6.10	6.84	7.44	5.10	5.27	5.86	6.38	1.82	2.00	2.25	2.45	2.91	3.39	3.82	4.17	1.09	1.39	1.58	1.72
	20	60	40	5.57	5.49	6.11	6.61	5.03	5.03	5.61	6.08	4.20	4.38	4.89	5.31	1.56	1.71	1.91	2.08	2.50	2.91	3.27	3.56	0.94	1.20	1.36	1.48
	40	10	20	3.31	3.12	3.17	3.18	2.89	2.77	2.83	2.86	2.39	2.34	2.42	2.45	0.84	0.88	0.91	0.93	1.32	1.46	1.53	1.57	0.47	0.58	0.61	0.64
	40	10	40	3.09	2.91	2.93	2.91	2.71	2.59	2.63	2.63	2.25	2.20	2.25	2.27	0.80	0.83	0.86	0.87	1.25	1.38	1.44	1.47	0.45	0.55	0.58	0.59
	40	35	20	5.13	4.99	5.41	5.75	4.53	4.47	4.87	5.19	3.78	3.82	4.17	4.45	1.35	1.46	1.60	1.71	2.14	2.45	2.70	2.90	0.79	1.00	1.11	1.19
	40	35	40	4.37	4.24	4.55	4.80	3.91	3.85	4.15	4.39	3.30	3.33	3.61	3.83	1.19	1.28	1.40	1.49	1.90	2.17	2.38	2.54	0.70	0.89	0.98	1.05
	40	60	20	6.95	6.86	7.66	8.31	6.17	6.18	6.91	7.51	5.17	5.29	5.93	6.45	1.85	2.03	2.28	2.48	2.95	3.45	3.88	4.23	1.10	1.42	1.60	1.75
	40	60	40	5.65	5.57	6.18	6.68	5.11	5.10	5.68	6.15	4.35	4.45	4.97	5.39	1.59	1.74	1.95	2.11	2.55	2.97	3.33	3.62	0.96	1.23	1.38	1.51
MC	20	10	20	0.66	0.83	0.95	1.04	0.56	0.69	0.76	0.81	0.48	0.56	0.61	0.64	0.26	0.29	0.31	0.32	0.17	0.18	0.20	0.20	0.12	0.13	0.13	0.14
	20	10	40	0.60	0.75	0.85	0.94	0.50	0.61	0.67	0.71	0.42	0.49	0.53	0.55	0.23	0.25	0.27	0.28	0.15	0.16	0.17	0.17	0.11	0.11	0.12	0.12
	20	35	20	1.10	1.39	1.58	1.75	0.99	1.21	1.36	1.49	0.87	1.02	1.18	1.24	0.47	0.52	0.58	0.63	0.32	0.34	0.37	0.40	0.23	0.24	0.26	0.28
	20	35	40	0.87	1.10	1.26	1.39	0.77	0.94	1.05	1.14	0.67	0.78	0.87	0.94	0.36	0.40	0.44	0.48	0.24	0.26	0.28	0.30	0.17	0.18	0.20	0.21
	20	60	20	1.54	1.94	2.22	2.46	1.42	1.73	1.97	2.17	1.26	1.48	1.67	1.84	0.69	0.75	0.85	0.94	0.46	0.49	0.55	0.60	0.33	0.34	0.39	0.43
	20	60	40	1.15	1.45	1.66	1.83	1.04	1.26	1.43	1.57	0.91	1.07	1.21	1.32	0.50	0.55	0.62	0.67	0.33	0.35	0.40	0.43	0.24	0.25	0.28	0.30
	40	10	20	0.67	0.84	0.96	1.05	0.57	0.69	0.76	0.82	0.49	0.57	0.61	0.65	0.26	0.29	0.31	0.32	0.18	0.19	0.20	0.20	0.12	0.13	0.14	0.14
	40	10	40	0.60	0.76	0.86	0.95	0.51	0.61	0.67	0.72	0.43	0.50	0.54	0.56	0.23	0.26	0.27	0.28	0.15	0.16	0.17	0.18	0.11	0.11	0.12	0.12
	40	35	20	1.11	1.39	1.59	1.76	1.00	1.22	1.37	1.49	0.88	1.03	1.15	1.25	0.48	0.52	0.58	0.63	0.32	0.34	0.38	0.41	0.23	0.24	0.26	0.28
	40	35	40	0.88	1.11	1.27	1.40	0.78	0.94	1.06	1.15	0.67	0.79	0.87	0.94	0.37	0.40	0.45	0.48	0.24	0.26	0.29	0.31	0.17	0.18	0.20	0.21
	40	60	20	1.55	1.95	2.23	2.46	1.43	1.74	1.98	2.17	1.26	1.48	1.68	1.84	0.69	0.76	0.86	0.94	0.46	0.49	0.55	0.61	0.33	0.35	0.39	0.43
	40	60	40	1.16	1.46	1.67	1.84	1.05	1.27	1.44	1.58	0.92	1.07	1.21	1.33	0.50	0.55	0.62	0.68	0.33	0.36	0.40	0.44	0.24	0.25	0.28	0.30
HDG				1.44	5.41	5.77	7.04	1.33	5.12	5.90	7.29	1.25	4.89	6.01	7.52	1.19	3.77	4.81	6.04	1.25	3.89	4.80	5.01	1.38	2.65	3.27	4.10
HDD				0.83	0.63	0.57	0.58	0.83	0.61	0.56	0.54	0.83	0.60	0.53	0.52	0.83	0.60	0.52	0.51	0.83	0.59	0.52	0.50	0.83	0.60	0.52	0.50

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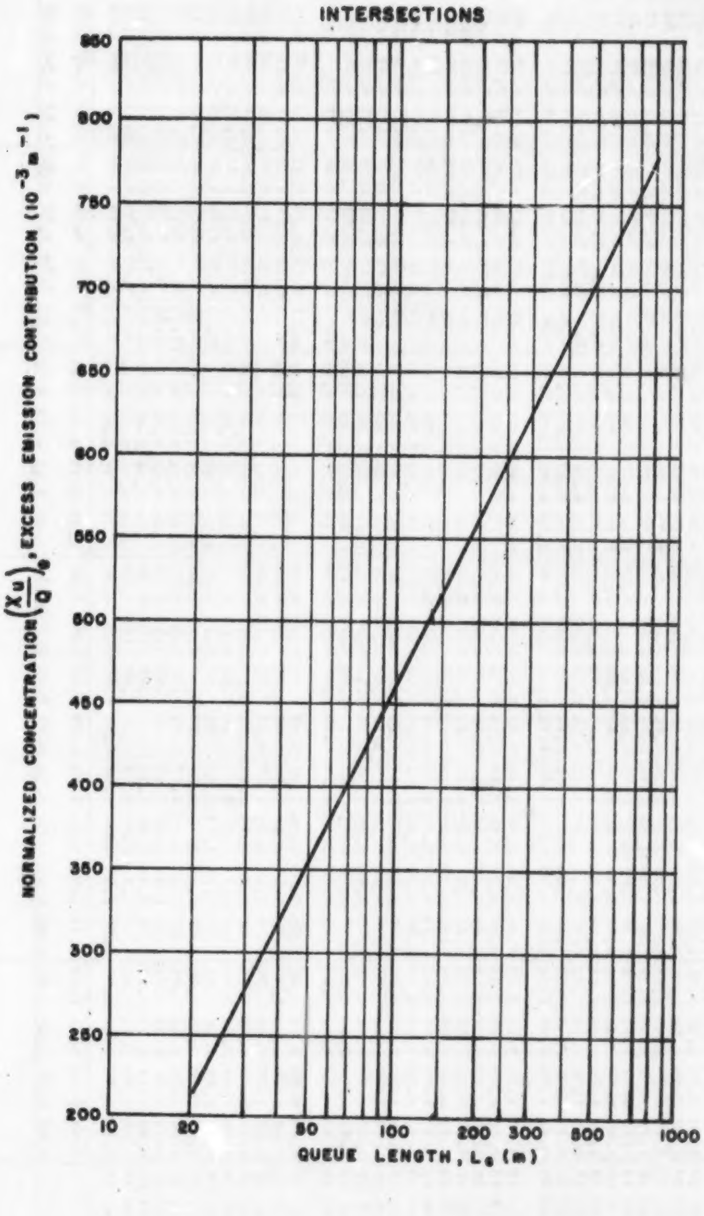


Figure 31. Normalized CO concentration contribution from excess emissions on approach 1 as a function of queue length on approach 1 for intersections

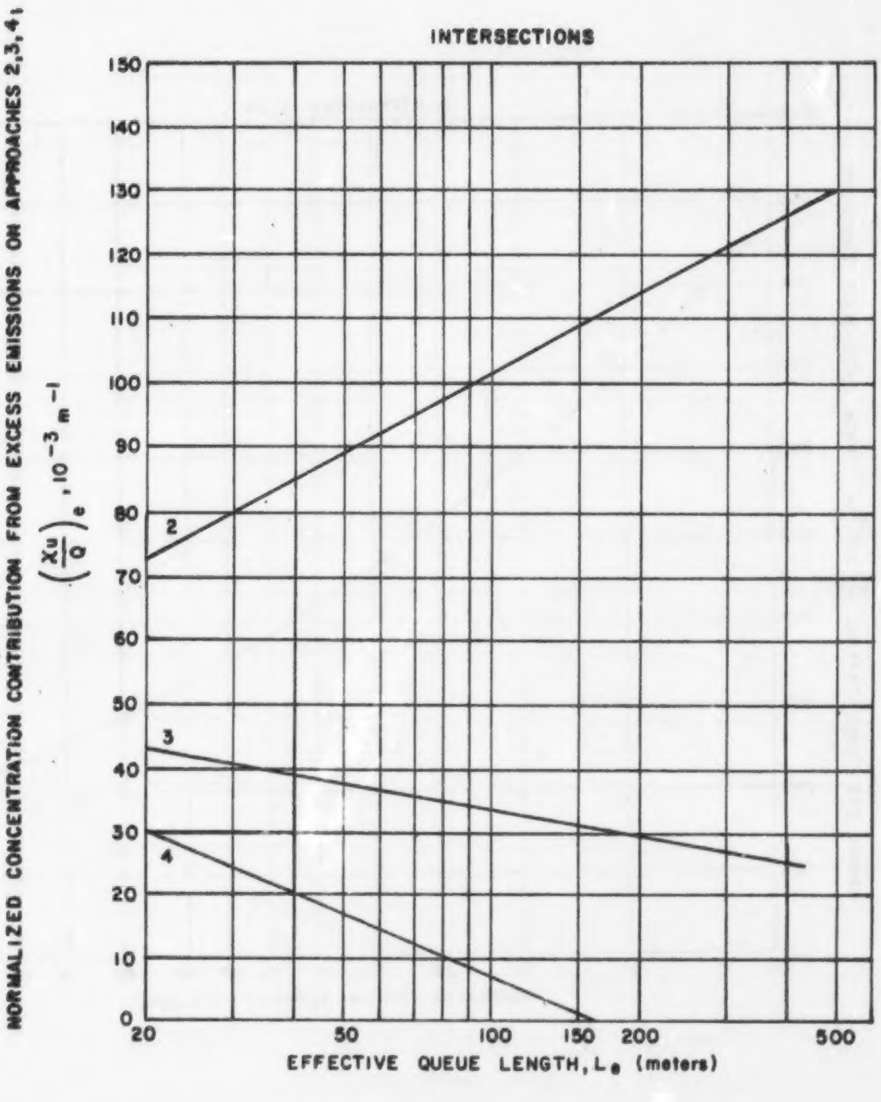


Figure 32. Normalized CO concentration contributions from excess emissions on approaches 2, 3, and 4 as a function of queue length on approach 1 for intersections

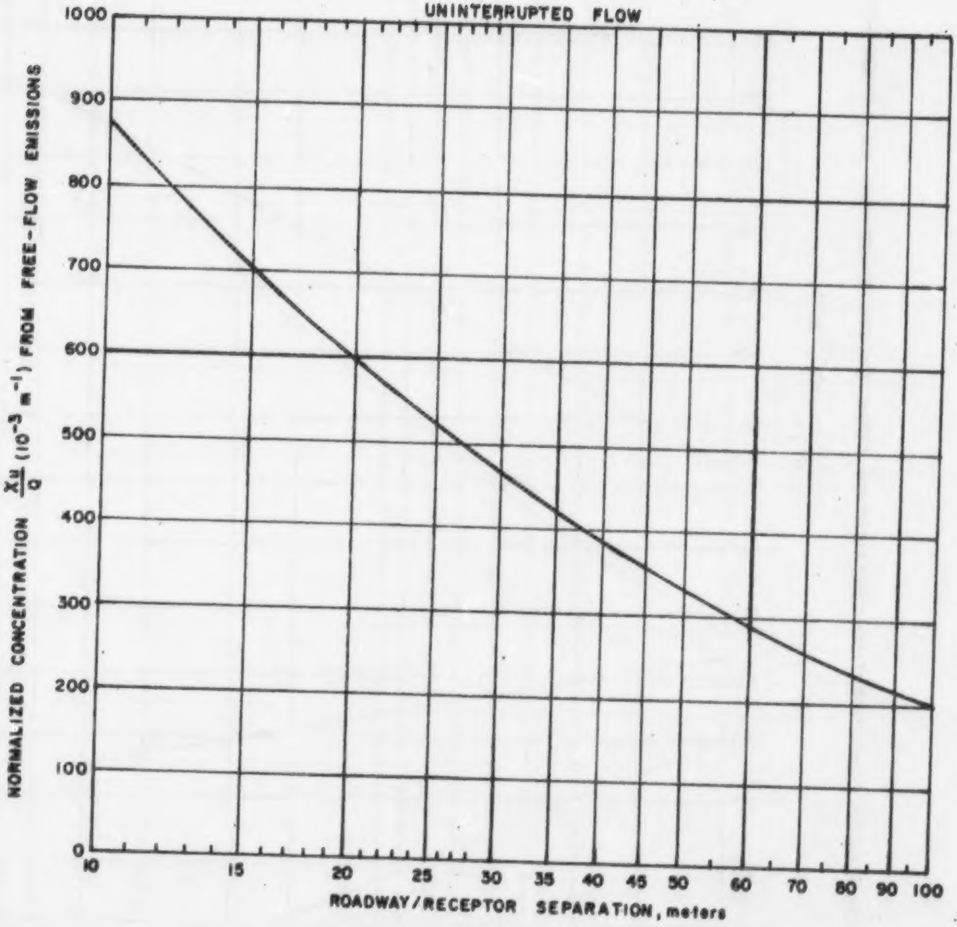


Figure 33. Normalized CO concentration contribution at each traffic stream at locations of uninterrupted flow

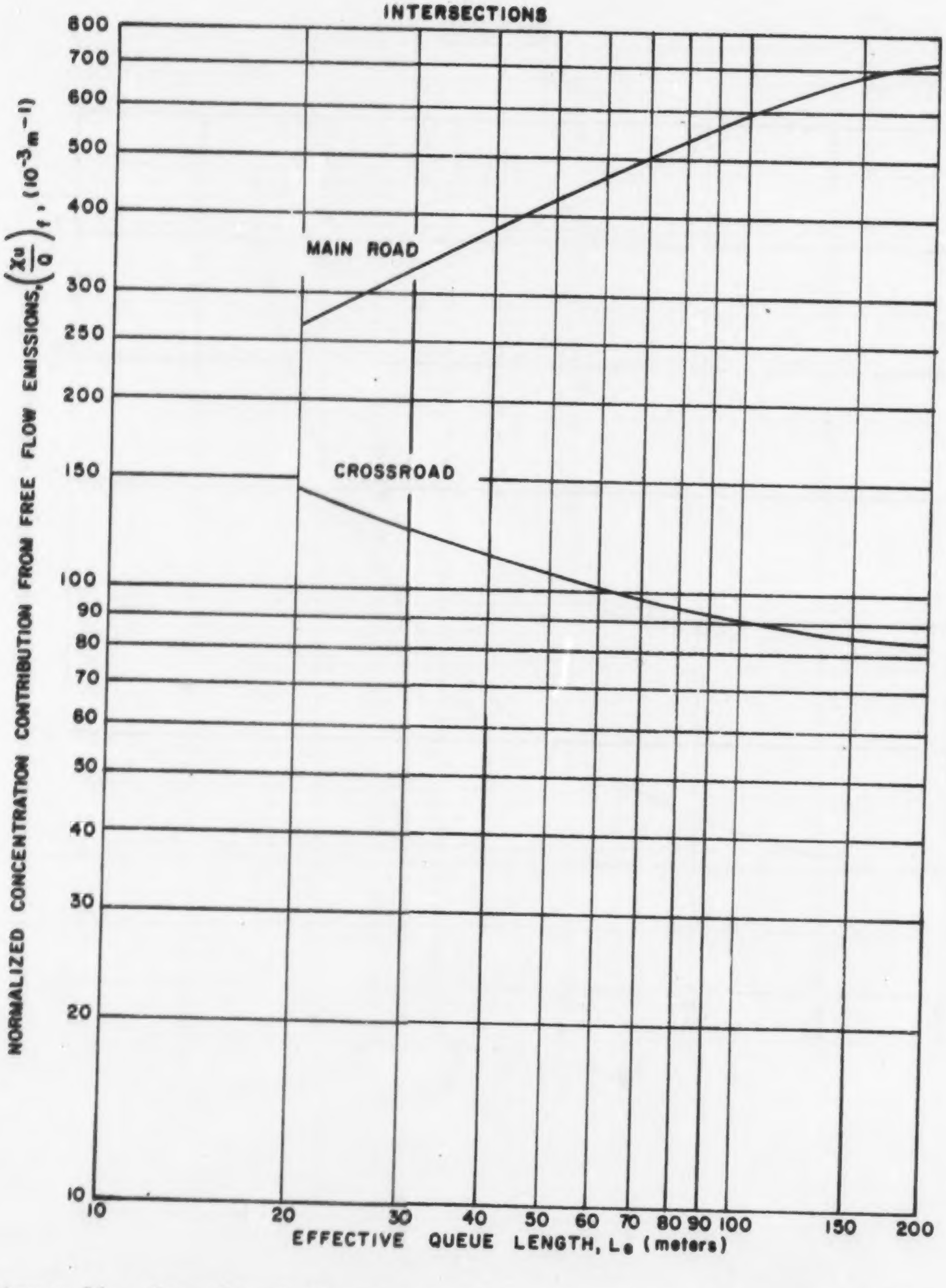


Figure 34. Normalized CO concentration contributions from free-flow emissions on each lane of roadways at intersections

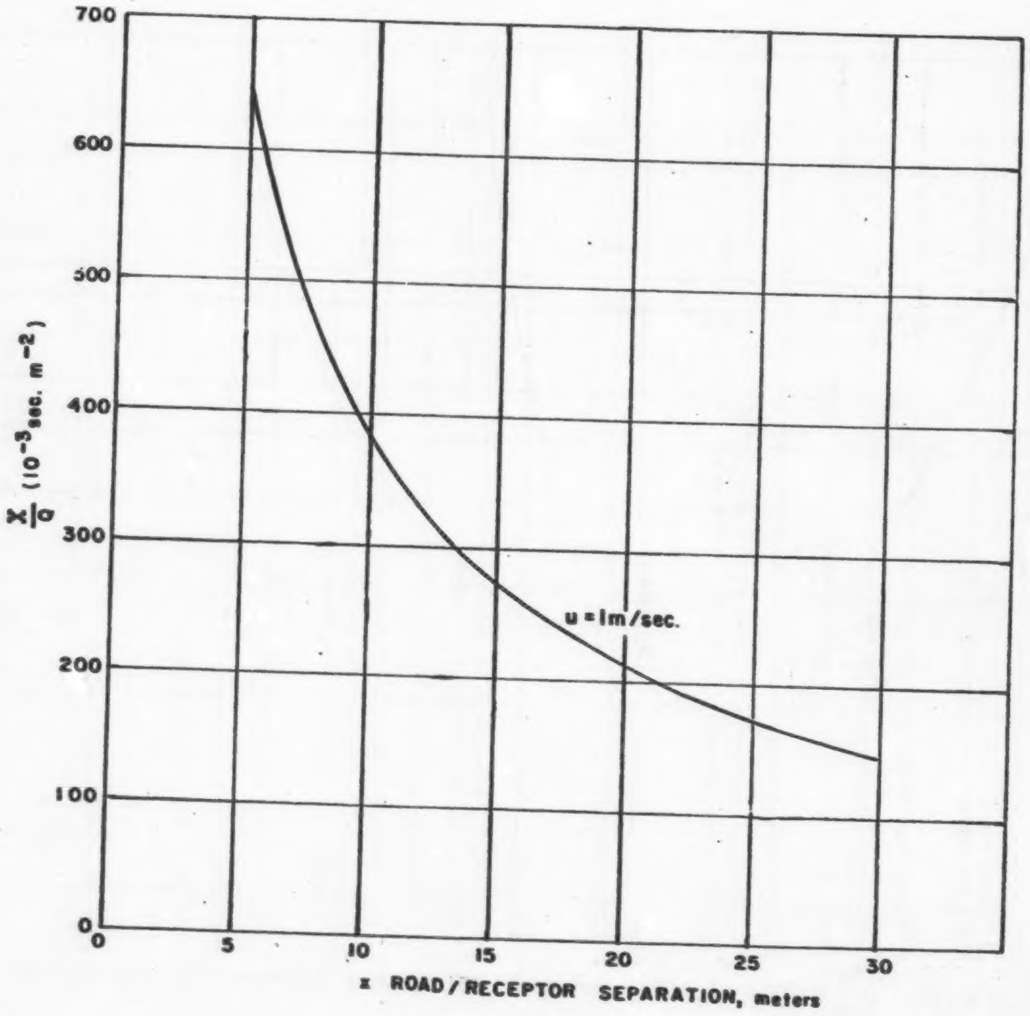


Figure 35. Normalized CO concentration in street-canyons assuming vortex has formed

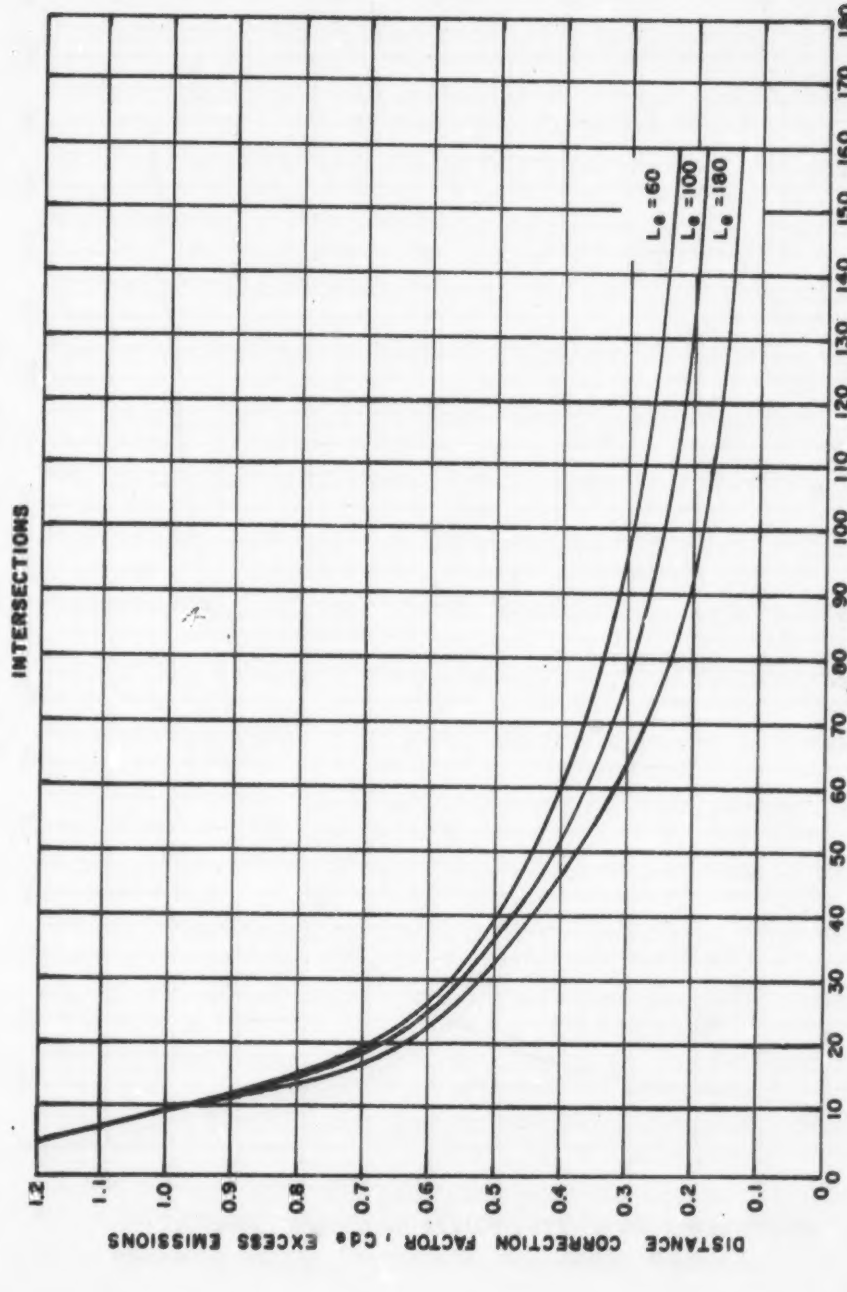


Figure 36. Distance correction factor for excess emission contributions at intersections

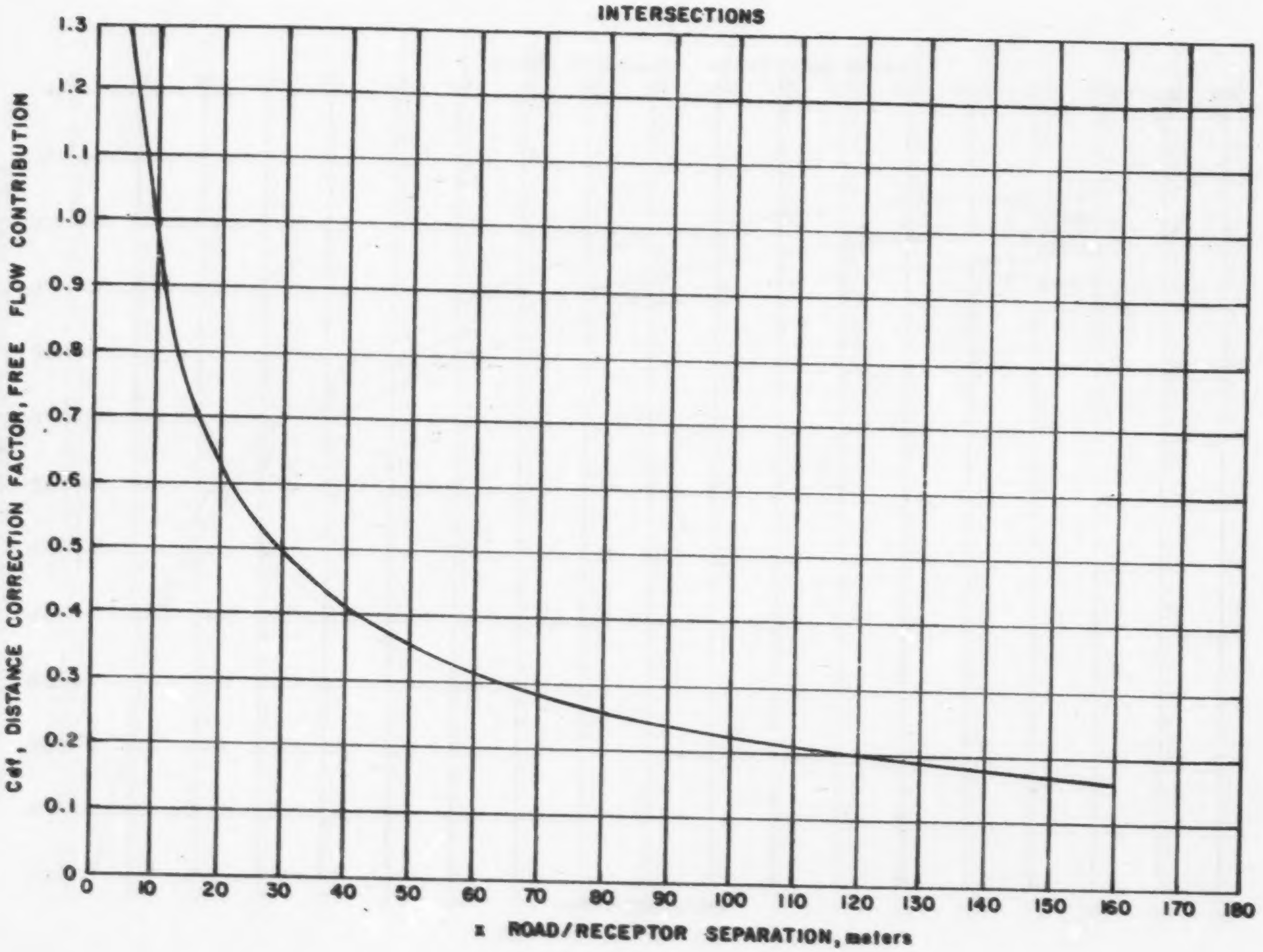


Figure 37. Distance correction factor for free-flow emission contributions at intersection locations

D. SPECIAL INSTRUCTIONS

Presented here are discussions on several topics that are directly relevant to hot spot analysis. These discussions serve to treat in detail several areas that are especially important in hot spot analysis, but which were only briefly discussed in previous sections of this document.

1. Optimum Receptor Siting

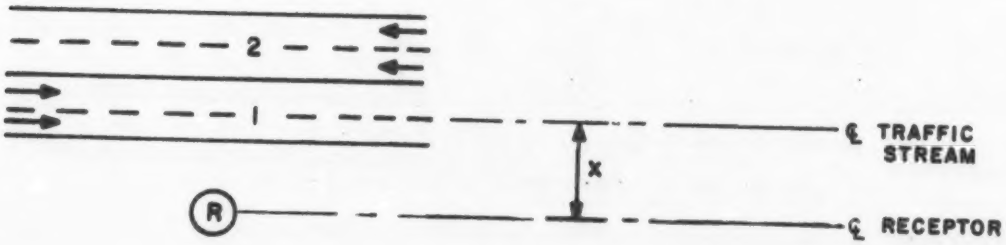
The location of the optimum receptor site is at the position where the maximum projected pollutant concentration is most likely to occur. The optimum receptor placement may be determined according to the following guidelines.

Uninterrupted flow locations:

(i) The optimum receptor site is on the side of the road that has the heaviest peak-hour traffic flow (vehicles/hour).

(ii) The receptor should be located at the minimum perpendicular distance, x, from the roadway consistent with the criteria for being a reasonable receptor site. For the purposes of hot spot verification, the most practical guidance that can be given is to assume the receptor to be located at the centerline of the adjacent sidewalk or at the right-of-way limit if no sidewalk exists.

(iii) Each traffic stream (all lanes in one direction of travel) should be assigned an identification number with regard to the receptor site as depicted below.



Intersection locations:

(i) The receptor should be located on an approach rather than the departure side of an intersection leg.

(ii) If all such approaches to the intersection have an equal number of approach lanes, the receptor should be located on the approach having the highest peak volume.

(iii) If the approaches have an unequal number of lanes, and the approach having the greatest number of lanes also has the highest lane volume, the receptor should be located on that approach.

(iv) If the approach having the largest number of lanes does not have the greatest lane volume, Table 9 and Figure 38 must be used to determine receptor placement. Enter Table 9 using the lane volume of the approach having the most lanes as V_{main} to determine the queue length, Le, which develops on that approach. Use this quantity to enter Figure 38 to determine the normalized concentrations, $\left(\frac{\chi u}{Q}\right)_e$. Next, designate the largest lane volume as V_{main} and enter Table 9 to determine the queue length which develops on the corresponding approach. Again use Figure 38 to find the resulting normalized concentration $\left(\frac{\chi u}{Q}\right)_e$. The receptor should be located on the approach which yields the highest $\left(\frac{\chi u}{Q}\right)_e$ value.

(v) Each traffic stream (all lanes in one direction of travel) approaching the intersection should be assigned an identification number with regard to the receptor site as depicted below.

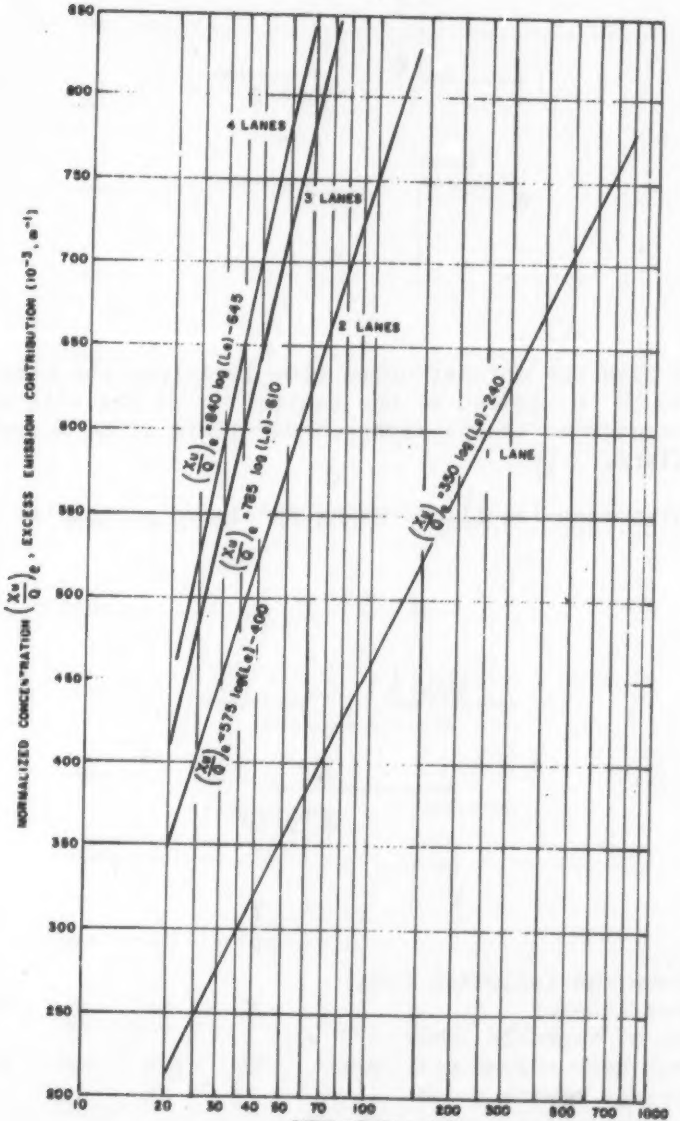
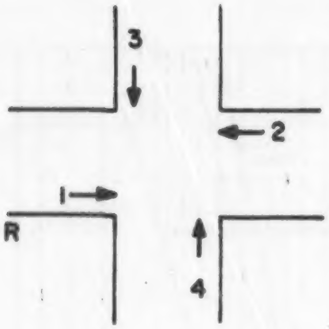


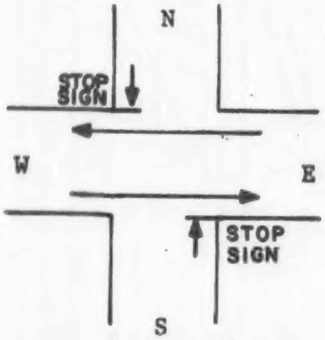
Figure 38. CO concentration contribution from excess emissions on approach 1 as a function of number of lanes and queue length



(vi) As with the uninterrupted flow location, the receptor should be located at the centerline of the adjacent sidewalk or at the right-of-way limit if no sidewalk exists.

Examples - Three examples illustrating the above principles are shown.

EXAMPLE 1



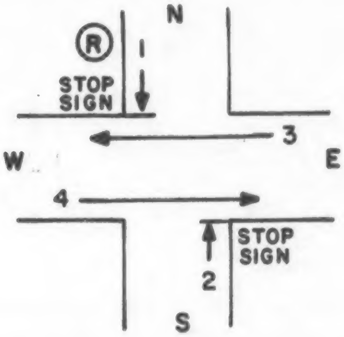
Given the following data:

Road segment	N	S	E	W
No. of approach lanes	1	1	1	1
Peak hour volume per lane	300	200	500	500
Average cruise speed	25	25	25	25
(assume intersection in an outlying business district)				

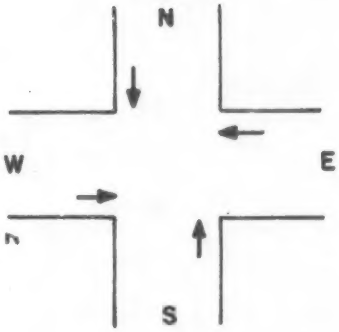
W-E roadway has uninterrupted flow. N-S roadway flow is controlled by a stop sign.

Solution:

Criterion (i) requires that the receptor be located on the N-S roadway. Since both N and S approaches have an equal number of lanes (1), the receptor should be located on the N approach according to criterion (ii). The traffic streams are then assigned identification numbers as depicted below according to criterion (v).



EXAMPLE 2

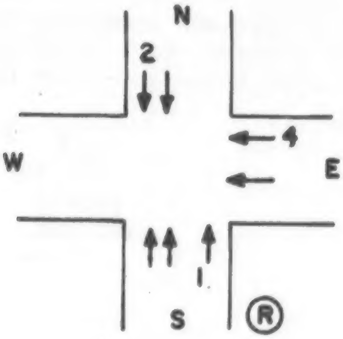


Road segment	N	S	E	W
No. of approach lanes	2	3	2	0
Peak hour volume per lane	500	600	500	-
Average cruise speed	25	25	25	-

Intersection controlled by a signal.

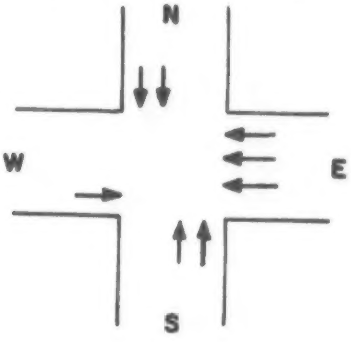
Solution:

The road segment having the greatest number of approach lanes (segment S) also has the highest peak hour lane volume. Hence, the receptor should be located on segment S based on criterion (iii) and the traffic streams identified as shown below.



Note: Since the crossroad (E-W) is a one-way street, segment W has no approach lanes and need not be considered in the subsequent analysis. However, segment E is still assigned the No. 4 identification number due to its relative position with respect to approach No. 1 (segment S).

EXAMPLE 3



Road segment	N	S	E	W
No. of approach lanes	2	2	3	1
Peak hour volume per lane	800	900	600	600
Average cruise speed	35	35	35	35

Intersection controlled by a signal.

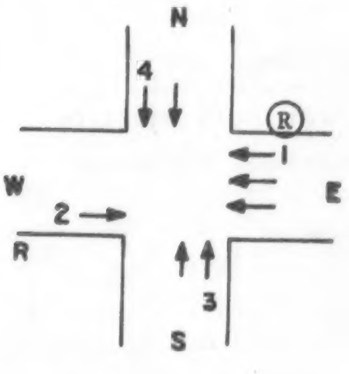
Solution:

Since the road segment having the greatest number of approach lanes (segment E) does not have the greatest lane volume (segment S), a test must be made according to criterion (iv) to determine the location of the highest expected CO concentration.

(a) First designating approach E as the main road: Vmain = 600 and Vcross = 900. Enter Table 8 at cruise speed 35 and the appropriate lane volumes. The resulting queue length, Le, on approach E is 231.0 m. Enter Figure 33 at Le = 231 m and read the $(\chi u/Q)e$ value at the intersection of Le = 231 and "3-lanes" line or calculate the $(\chi u/Q)e$ value from the appropriate equation. In this case, the equation must be used, so $(\chi u/Q)e = 785 \log (Le) - 610$ for a 3-lane approach and $(\chi u/Q)e = 1245.4$ in this case.

(b) Next designate approach S as the main road: Vmain = 900 and Vcross = 600. Again use Table 8 to determine the queue length on approach S (283.9 m). Enter Figure 33 at Le = 283.9 m and read the value of $(\chi u/Q)e$ at the intersection of Le = 283.9 and the "2 lanes" line or calculate the value from the equation. Once again, the equation must be used: $(\chi u/Q)e = 575 \log (Le) - 400$ for a 2-lane approach and $(\chi u/Q)e = 1010.6$ in this case.

(c) The $(\chi u/Q)e$ value is maximized by locating the receptor on segment E. The traffic streams approaching the intersection should be identified as depicted below.



2. Cruise Speed

It is recognized that travel speed data are not always readily available and that the effort required to actually measure travel speed is rather substantial. Offered here are alternative methods for deriving reasonable (in the context of hot spot analysis) estimates of cruise speed for various types of roadways. These methods involve a rather subjective process of defining speed as a simple function of lane volume. Figures 39 and 40 present specific speed-lane volume relationships that may be used for estimating cruise speeds on free-flowing sections of expressways at rural arterial streets. Table 13 provides suggested ranges of speeds for urban streets in several settings. Again, the speed estimates derived from these should be used only in the absence of measured data.

3. Cold Starts

It is likely that information regarding the percentages of vehicles operating in the cold mode will not be directly available for most areas; therefore, this parameter must be estimated. A study[13] of the percentages of vehicles operating in the cold mode at 60 locations in two major U.S. cities provides the basis for the following general guidance for estimating the fraction of cold operating vehicles as a function of facility type and location.

Location and street type	Range of percent of vehicles* operating in the cold-start mode
• CBD and fringe area; all facilities	40 to 70 percent
• Outer areas; arterials, collectors, locals	30 to 60 percent
• Core area expressways	15 to 30 percent
• Outer expressways	0 to 20 percent
• Indirect sources	40 to 60 percent

*Reflects afternoon peak travel hour conditions.

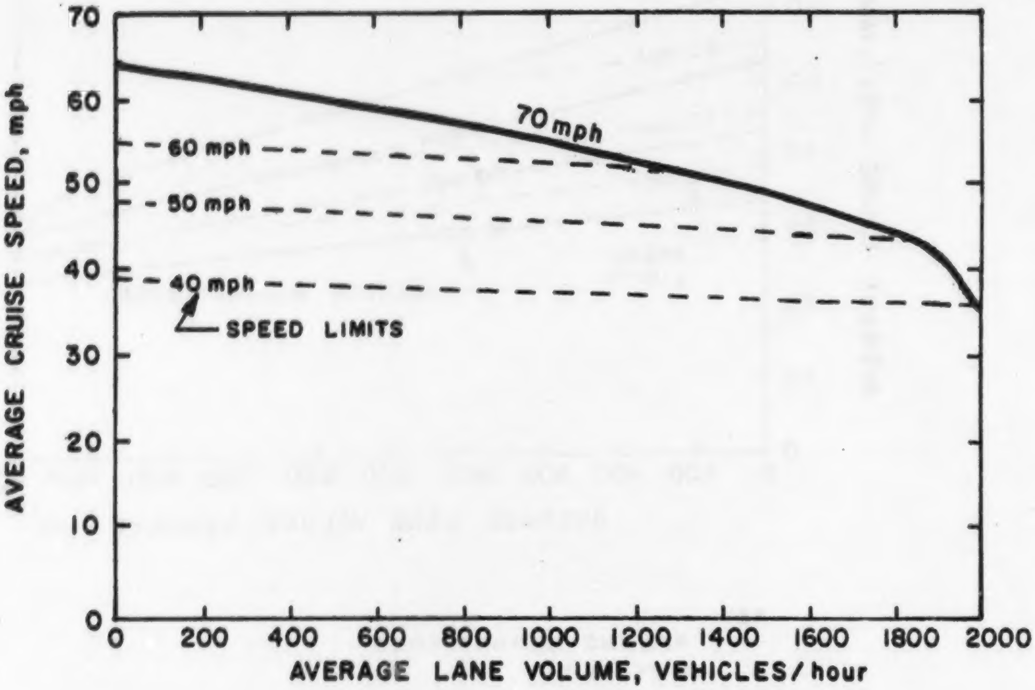


Figure 39. Typical relationships between average lane volume and average speed in one direction of travel on controlled access expressways under uninterrupted flow conditions[1]

Note: Minimum design standards for controlled access expressways typically specify design speeds of 70 mph or higher. It should be emphasized that design speed is used to establish minimum geometric standards to provide a factor of safety in comparison to the legal speed limits which control vehicle operation.

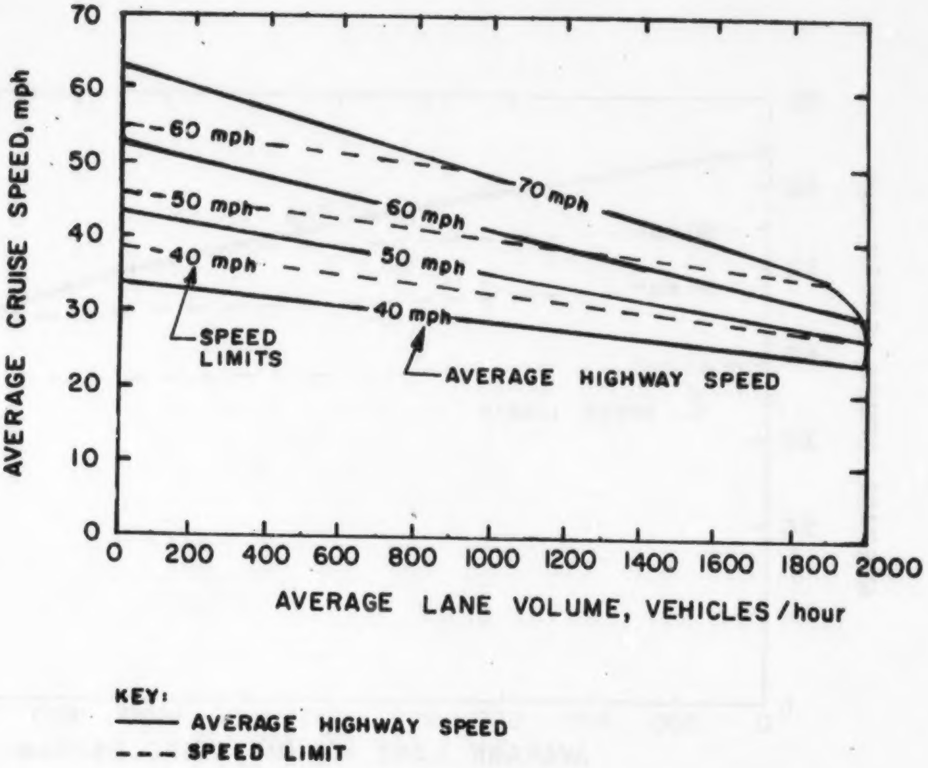


Figure 40. Typical relationships between average lane volume and average speed in one direction of travel on multilane rural highways under uninterrupted flow conditions[1]

Note: Average Highway Speed is the maximum speed at which a driver can comfortably travel over the stretch of roadway under favorable weather and zero volume conditions and maintain safe vehicle operation. Here again the Average Highway Speed represents the roadway design speed. (The legal speed limit cannot be higher than the Average Highway Speed.)

Table 13. CRITERIA FOR SELECTION OF CRUISE SPEED VALUES FOR URBAN ROADWAYS AND INTERSECTIONS

General location	Operating characteristics	Cruise speed range, mph
Central business district; Fringe business district	Much interference and friction from pedestrians or parking and unparking vehicles; closely spaced intersections; individual vehicle speed nearly always controlled by speed of the entire traffic stream	15 - 20
Outlying business district; Dense residential/commercial land use	Occasional interference and friction from pedestrians or parking and unparking vehicles; nearby intersections occasionally restrict flow; individual vehicle speed somewhat controlled by speed of entire traffic stream	20 - 30
Outlying and residential residential/commercial land use	Infrequent interference or friction from pedestrians or maneuvering vehicles, no interference form downstream intersections; speed of individual vehicle mildly influenced by speed of traffic stream	25 - 35

E. EXAMPLE

An example of the hot spot verification procedure for a signalized intersection, School Street at Lexington Street, is presented here. This example makes use of Worksheet No. 5, Calculation of CO Concentration at Intersections. A completed worksheet is presented in Figure 41. Figure 42 provides a sketch of the intersection indicating the orientation of the approaches and the location of the optimum receptor site.

The first six entries are concerned with recording the data required to perform the hot spot verification. The Lexington Street north approach has the highest volume; thus, the optimum receptor site is positioned along this approach. The G/Cy of 0.53 for the Lexington Street approach is recorded in line 7.b.i and used with the approach volume, 455, to compute the effective crossroad volume of 330 vehicles per hour. These two volumes are entered on the appropriate section of Table 9 to determine the queue length (line 8).* The free flow emission rate is found in Table 10 for each approach and entered on line 9. For this example, the queue length is 41m, and the free flow emission rates in g/m-sec are 0.00392, 0.00278, 0.00227, and 0.00248 for the four approaches.

The normalized concentrations are found using curves in Figure 34, as appropriate and entered in line 10. The distance correction factors, line 12, are obtained from Figure 37 at the appropriate roadway/receptor separation distance for the Main Road approaches only; the correction factor for the cross-street approaches equals 1.0. Since the emission rates provided in the verification represent a specific set of assumptions regarding calendar year, vehicle, type distribution, cold- and hot-start percentages, etc., a correction factor must be applied to reflect actual conditions (i.e., the "assumed" actual conditions, which here, are those indicated in the heading data). This factor is determined using Table 12,

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*These volumes are also used later with Table 9 to determine the excess emission rate.

WORKSHEET NO. 5

CALCULATION OF CO CONCENTRATIONS AT INTERSECTIONS

Location: School St. @ Lexington St. Waltham, MA. Date: 21 May 1978

Analysis by: T. Midurski Checked by: TPM

Assumptions: Analysis Year: 1982 .

Location: ______ California; X 49 State, low altitude;

______ 49-State, high altitude.

Ambient temperature: 20 °F.

Percent of vehicles operating in: (a) cold-start mode 10 ;

hot-start mode 20 .

Vehicle-type distribution: LDV 78 %; LDT 11 %; HDV-G 6 %;

HDV-D 5 %; MC 0 %.

	Main road		Crossroad	
1. Site identification	Lexington St.		School St.	
2a. i - Intersection approach identification	1 N	2 S	3 E	4 W
2b. - Is approach located in a street canyon	NO	NO	NO	NO
3. n_i - Number of traffic lanes in approach i	1	1	1	1
4. x_i - Roadway/receptor separation (m)	4	8		
5. V_i - Peak-hour lane volume in each approach (veh/hr)	455	325	260	290
6. S_i - Cruise speed (mph) on each approach	15	15	15	15
7. a. Type of intersection (signalized or unsignalized)	SIGNALIZED			
b. For signalized intersections:				
i) $(G/Cy)_1$ - Green time/signal cycle ratio for approach 1	0.53			
ii) V_{cross} - Effective crossroad volume (veh/hr)			330	
8. Le - Queue length on approach 1 (m)	41			

Figure 41. Example Hot Spot Verification

1/9

		Main road		Crossroad	
9.	Qf_i - Free-flow emission rate (g/m-sec)	0.00392	0.00278	0.00227	0.00248
10.	$\left(\frac{\chi u}{Q}\right)_{f,main}$ - Normalized concentration contribution from free-flow emissions on main roadway (10^{-3} m^{-1})	380			
11.	$\left(\frac{\chi u}{Q}\right)_{f,cross}$ - Normalized concentration contribution from free-flow emission on crossroad (10^{-3} m^{-1})			120	
12.	Cdf_i - Distance correction factor, free-flow emissions	1.30	1.15		
13.	C_{Ef} - Emissions correction factor, free-flow emissions.	1.33	1.33	1.33	1.33
14.	a. $\chi_{f,main}$ - Concentration contribution from free-flow emissions on main road (mg/m^3)	4.2			
	b. $\chi_{f,cross}$ - Concentration contribution from free-flow emissions on crossroad (mg/m^3)			0.8	
15.	χ_f - Total concentration from free-flow emissions (mg/m^3)	5.0			
16.	Q_e - Excess emission rate (g/m-sec)	0.02065			
17.	$\left(\frac{\chi u}{Q}\right)_{e,i}$ - Normalized concentration contribution from excess emissions on approach i ($10^{-3}m^{-1}$)	320	85	40	20
18.	Cde_i - Distance correction factor, excess emissions	1.25	1.35	1.0	1.0
19.	C_{Ee} - Emissions correction factor, excess emissions	0.96	0.96	0.96	0.96
20.	$\chi_{e,i}$ - Concentration contribution from excess emissions on approach i (mg/m^3)	9.6	2.8	1.0	0.5
21.	χ_e - Total contribution from excess emissions (mg/m^3)	13.9			
22.	$\chi_{E,1\text{-}hr}$ - 1-hour average concentration resulting from vehicle emissions (mg/m^3)	18.9			

Figure 41 (continued). Example Hot Spot Verification

23. $\chi_{E,\ 8\text{-hr}}$ - 8-hour average CO concentration (mg/m^3) 13.2

24. $\chi_{B,8\text{-hr}}$ - 8-hour average background concentration (mg/m^3) 3.6

25. $\chi_{T,8\text{-hr}}$ - Total CO concentration, 8-hour average (mg/m^3) 16.8

26. $\chi_{T,8\text{-hr}}$ - Total CO concentration, 8-hour average (ppm) 14.6

Figure 41 (continued). Example Hot Spot Verification

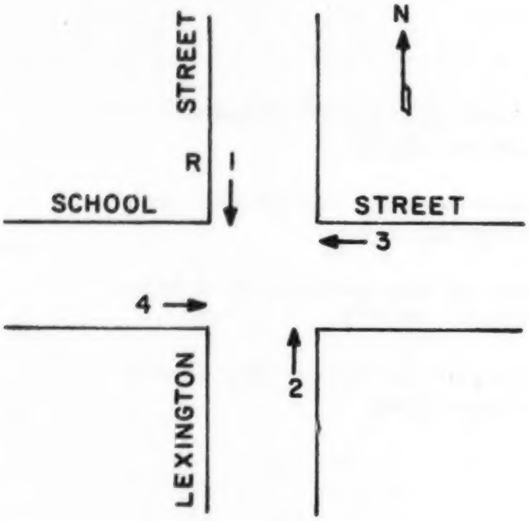
N
STREET
R
1
SCHOOL
STREET
3
4
2
LEXINGTON

Figure 42. Approach orientation and receptor (R) location

for 49-state, low altitude conditions and the conditions described in the heading data regarding analysis year, location, etc., for each vehicle type. The individual correction factors for each vehicle type are then weighted according to the actual percentages observed (or assumed) in the traffic stream, and a composite factor is derived. In this example, the individual correction factors from Table 12 are: 0.83, 2.85, 5.23, and 0.6 for LDV's, LDT's, HDV-G's, and HDV-D's, respectively. Weighting these according to the percentages of each type of vehicle (from the heading data) yields:

$$C_{Ef} = (0.78)(0.83) + (0.11)(2.85) + (0.06)(5.23) + (0.05)(0.6) = 1.33$$

The concentration contribution from free-flow emissions is computed separately for each approach for both the main street and the cross street. For the main street approaches, the free-flow concentration, $\chi_{f,main}$, is computed from the following equation:

$$\begin{aligned}\chi_{f,main} &= \left[(\text{line } 10)(\text{line } 13)\right]\left[(\text{line } 3)_1(\text{line } 9)_1(\text{line } 12)_1 + \right.\\ &\left.(\text{line } 3)_2(\text{line } 9)_2(\text{line } 12)_2\right] = \\ &\left[(380)(1.33)\right]\left[(1)(0.00392)(1.3) + (1)(0.00278)(1.15)\right] = \\ &4.2 \text{ mg/m}^3\end{aligned}$$

For the cross-street contribution:

$$\begin{aligned}\chi_{f,cross} &= \left[(\text{line } 11)(\text{line } 13)\right]\left[(\text{line } 3)_3(\text{line } 9)_3 + (\text{line } 3)_4 (\text{line } 9)_4\right] = \\ &\left[(120)(1.33)\right]\left[(1)(0.00227) + (1)(0.00248)\right] = 0.8 \text{ mg/m}^3\end{aligned}$$

The total contribution, χ_f, from free-flow emissions is:

$$\chi_f = \chi_{f,main} + \chi_{f,cross} = 4.2 \text{ mg/m}^3 + 0.8 \text{ mg/m}^3 = 5.0 \text{ mg/m}^3$$

The next step is to compute the excess emissions correction factor. This factor is derived in the same manner that the free flow emissions correction factors are developed, except a speed of 0 mph is used in Table 12. The excess emissions correction factor thus derived is 0.96.

The excess emission rate, Q_E, is computed indirectly using cruise and queue component emission rates found in Table 9, and appropriate correction factors. The cruise component, Q_{QC}, and the total queue component, Q_{QT}, are obtained from Table 9 based on the highest main road volume of 455 vehicles (from line 5 on the Worksheet), and the effective crossroad volume of 330 vehicles (from line 7.b.ii. of the Worksheet). The correction factors applied to Q_{QC} and Q_{QT} are the free flow emissions correction factor, C_{Ef} (from line 13 of the Worksheet), and the excess emissions correction factor, C_{Ee} (from line 19 of the Worksheet), respectively. The actual excess emission rate, Q_E, is then computed by:

$$Q_e = (Q_{QT})(C_{Ee}) - (Q_{QC})(C_{Ef}) =$$

$$(0.02302)(0.96) - (0.00221)(1.33) = 0.01916$$

The normalized concentration contribution from excess emissions for each approach is determined using Figures 31 and 32, and distance correction factors are computed for the main street approaches using Figure 36. The above data are used to compute the excess emissions contribution for each approach, χ_{ei}, from:

$$\chi_{ei} = (Q_e)\left(\frac{\chi n}{Q}\right)_{ei} (Cde)_i$$

The total concentration from excess emissions, then is:

$$\chi_e = \sum_{n-1}^{4} \chi_{ei}$$

In this example, χ_e was found to be 11.1 mg/m^3. The total 1-hour average concentration, then, is:

$$\chi_f + \chi_e = 5.0 + 11.1 = 16.1 \ mg/m^3$$

The 8-hour average CO concentration is computed as the product of 16.1 (the 1-hour average) and 0.7 (a correlation factor), which yields 11.3 mg/m^3; this value is recorded on line 23. The 11.3 mg/m^3 concentration is the local traffic contribution to which a background concentration, 2.9 mg/m^3, is added to determine the total 8-hour average CO concentration, which is 14.2 mg/m^3. To convert the concentration from mg/m^3 to ppm, 14.2 mg/m^3 is multiplied by 0.87, which yields 12.4 ppm; this is entered on line 29.

The results of the verification indicate a hot spot potential at the Lexington Street - School Street intersection. The highest likely 8-hour average CO concentration computed for the north approach of Lexington Street is 14.2 mg/m^3 (12.4 ppm).

SECTION V

ADDITIONAL INFORMATION REGARDING THE HOT SPOT GUIDELINES

A. INTRODUCTION

This section provides additional information on two aspects of screening and verification that are not in the mainstream of the screening and verification procedures, and hence were mentioned only briefly in earlier sections. These topics include:

- Refined estimates of background concentrations
- Estimating the frequency of violations of the NAAQS.

B. BACKGROUND CO CONCENTRATIONS

1. Background Concentrations

In Section IV, suggested background concentrations were given for use with the verification procedure. These concentrations were recommended for cases where data are unavailable to develop specific local background estimates. This discussion presents a technique for estimating area-specific background concentrations, thus bridging a gap between assuming a universally applicable value and using the more involved techniques for finding a site-specific background concentration estimate that are presented in EPA's Indirect Source Guidelines.[16,21]

The following technique uses the bulk CO emission inventory for a region together with a simple urban dispersion model.[22] The bulk CO emission inventory can be obtained either from the total VMT and the FTP emission factor for the appropriate vehicle age mix, or from published data for metropolitan AQCR's.[23] Published data for AQCR's that do not fall in a metropolitan area are not appropriate because emissions in these regions do not display enough areal homoegneity to fit the assumptions of the simple urban dispersion model used in the following technique.

2. Estimating Bulk Emissions from VMT data

VMT data are perhaps the most abundant data elements available concerning a road network. They are normally available from state or regional transportation, planning, or highway departments. All that is required is the total VMT for the region. Once this number is obtained, it is multiplied by the grams per vehicle mile measured by the FTP for the vehicle age mix appropriate for the region of interest. National average data may be used if the local vehicle age mix cannot be obtained. This number (grams of carbon monoxide) should then be divided by the land area coinciding with the area covered by the VMT data, and the number of seconds during the time period for which the VMT apply (generally 1 year). The resulting number is the average area emission rate (gm/m^2 sec). Multiplying by 1000, then, yields emissions in mg/m^2 sec.

Alternatively, data are available for 1970 from the report entitled The National Air Monitoring Program: Air Quality and Emissions Trends Annual Report Volume II.[23] Carbon monoxide emission data are given in tons/year/km^2 by AQCR. Multiplying the listed emission rate by 2.88×10^{-5} converts the emissions to mg/m^2 sec.

Emissions calculated by either method should be multiplied by 3/2, since the bulk of CO emissions from traffic occur approximately between the hours of 6 a.m. and 10 p.m.

3. Background Concentrations Estimates

The method presented below is similar to that given by Hozworth[21] for estimating areal averaged concentrations as a function of mixing height, H, windspeed, u, and downwind distance from the upwind edge of the region, S. The major assumptions of this technique are that:

1. Steady-state conditions prevail.
2. Emissions occur at ground level and are uniform over the region.
3. Pollutants are nonreactive.
4. Vertical diffusion from each elemental source conforms to neutral or stable conditions and concentrations follow a Gaussian distribution out to a defined travel time that is a function of H. Thereafter, a uniform vertical distribution of pollutant occurs as a result of further dispersion within the mexiing layer.

In the model, two separate stability classes have been assumed with diffusion coefficients for these classes based on those used in both APRAC-1A[24] and APRAC-2[25] urban diffusion models. Given as a function of travel time, these coefficients are:

D stability $\sigma_z = 0.5t^{0.77}$

E stability $\sigma_z = 1.35t^{0.51}$

where t is the travel time in seconds.

The model treats the city source as a continuous series of infinitely long cross-wind line sources with pollutants confined within the mixing layer. As indicated in assumption 5, the model requires two equations according to whether none or some of the pollutants emitted at ground level achieve a uniform vertical distribution within the mixing layer before being transported beyond the downwind edge of the city. The equations are

$$\overline{\chi/Q} = 5.641(S/u)^{0.23} \qquad \text{D stability} \qquad (10a)$$

$$\chi/Q = 0.810(S/u)^{0.49} \qquad \text{E stability} \qquad (10b)$$

when none of the pollutants achieve a uniform vertical distribution, that is, when

$$S/u \leq 1.841H^{1.30} \qquad \text{D stability}$$

$$S/u \leq 0.358H^{1.96} \qquad \text{E stability}$$

The units are in meters and seconds, with $\overline{\chi/Q}$ being sec/m. When S/u is greater than the indicated value, some of the pollutant achieves a uniform vertical distribution and the equations become:

$$\chi/Q = 6.143H^{0.3} + \frac{S}{2uH} - 1.053\,\frac{uH^{1.6}}{S} \qquad \text{D stability} \qquad (11a)$$

$$\text{and } \chi/Q = 0.371H^{0.96} + \frac{S}{2uH} - 0.22\,\frac{uH^{2.92}}{S} \qquad \text{E stability} \qquad (11b)$$

Tables 14 and 15 give solutions to Equations (10a) or (11a) and (10b) or (11b), respectively, for various combinations of windspeed, mixing height, and travel distance across the region. Values below and to the right of the dotted lines for each city size are from Equations (10a) and (10b). Other values are found using (11a) and (11b).

To calculate the average background concentration, enter the table at the appropriate mixing height, windspeed, and travel distance to find the value of $\overline{\chi/Q}$. Multiplying this number by the emission rate found earlier yields the areal averaged, background CO concentration.

4. Example Applications

As a first example, consider the Boston AQCR. The Trends Report[23] gives a 1970 emission rate of 178.75 tons/yr/km^2 of CO. Multiplying by 2.88×10^{-5} converts this to 5.15×10^{-3} mg/m^{2}sec. Using Table 14 for D stability,

Table 14. AREAL AVERAGED NORMALIZED CONCENTRATION (SEC/M) -- D STABILITY

CITY SIZE (KM)	WIND SPEED (M/SEC)	MIXING HEIGHT (M)									
		50	100	150	200	250	300	350	400	450	500
10	1	120.	74.	61.	55.	51.	50.	49.	48.	48.	47.
	2	70.	49.	44.	42.	41.	40.	40.	40.	40.	40.
	3	53.	41.	38.	37.	37.	37.	36.	36.	36.	36.
	4	45.	36.	35.	34.	34.	34.	34.	34.	34.	34.
	5	40.	34.	33.	33.	32.	32.	32.	32.	32.	32.
20	1	220.	124.	94.	80.	72.	67.	64.	61.	60.	59.
	2	120.	74.	61.	55.	51.	50.	49.	48.	48.	47.
	3	86.	58.	49.	46.	44.	44.	43.	43.	43.	43.
	4	70.	49.	44.	42.	41.	40.	40.	40.	40.	40.
	5	60.	44.	40.	39.	38.	38.	38.	38.	38.	38.
30	1	320.	174.	128.	105.	92.	84.	78.	74.	71.	69.
	2	170.	99.	77.	67.	62.	58.	56.	55.	54.	53.
	3	120.	74.	61.	55.	51.	50.	49.	48.	48.	47.
	4	95.	62.	52.	48.	46.	45.	45.	44.	44.	44.
	5	80.	54.	47.	44.	43.	42.	42.	42.	42.	42.
40	1	420.	224.	161.	130.	112.	100.	92.	87.	82.	79.
	2	220.	124.	94.	80.	72.	67.	64.	61.	60.	59.
	3	153.	91.	72.	63.	58.	55.	54.	53.	52.	51.
	4	120.	74.	61.	55.	51.	50.	49.	48.	48.	47.
	5	100.	64.	54.	49.	47.	46.	45.	45.	45.	45.
50	1	520.	274.	194.	155.	132.	117.	107.	99.	94.	89.
	2	270.	149.	111.	92.	82.	75.	71.	68.	65.	64.
	3	186.	108.	83.	71.	65.	61.	59.	57.	56.	55.
	4	145.	87.	69.	61.	57.	54.	52.	51.	51.	50.
	5	120.	74.	61.	55.	51.	50.	49.	48.	48.	47.
60	1	620.	324.	228.	180.	152.	134.	121.	112.	105.	99.
	2	320.	174.	128.	105.	92.	84.	78.	74.	71.	69.
	3	220.	124.	94.	80.	72.	67.	64.	61.	60.	59.
	4	170.	99.	77.	67.	62.	58.	56.	55.	54.	53.
	5	140.	84.	67.	60.	56.	53.	52.	51.	50.	50.
70	1	720.	374.	261.	205.	172.	151.	135.	124.	116.	109.
	2	370.	199.	144.	117.	102.	92.	85.	80.	77.	74.
	3	253.	141.	105.	88.	79.	72.	68.	66.	64.	62.
	4	195.	112.	86.	74.	67.	63.	60.	58.	57.	56.
	5	160.	94.	74.	65.	60.	57.	55.	53.	53.	52.
80	1	820.	424.	294.	230.	192.	167.	150.	137.	127.	119.
	2	420.	224.	161.	130.	112.	100.	92.	87.	82.	79.
	3	287.	158.	116.	97.	85.	78.	73.	70.	67.	65.
	4	220.	124.	94.	80.	72.	67.	64.	61.	60.	59.
	5	180.	104.	81.	70.	64.	60.	58.	56.	55.	54.
90	1	920.	474.	328.	255.	212.	184.	164.	149.	138.	129.
	2	470.	249.	178.	142.	122.	109.	100.	93.	88.	84.
	3	320.	174.	128.	105.	92.	84.	78.	74.	71.	69.
	4	245.	137.	102.	86.	77.	71.	67.	65.	63.	61.
	5	200.	114.	87.	75.	68.	63.	61.	59.	57.	56.
100	1	1020.	524.	361.	280.	232.	201.	178.	162.	149.	139.
	2	520.	274.	194.	155.	132.	117.	107.	99.	94.	89.
	3	353.	191.	139.	113.	99.	89.	83.	76.	75.	72.
	4	270.	149.	111.	92.	82.	75.	71.	68.	65.	64.
	5	220.	124.	94.	80.	72.	67.	64.	61.	60.	59.

Table 15. AREAL AVERAGED NORMALIZED CONCENTRATION (SEC/M) — E STABILITY

CITY SIZE (KM)	WIND SPEED (M/SEC)	MIXING HEIGHT (M)									
		50	100	150	200	250	300	350	400	450	500
10	1	116.	79.	74.	74.	74.	74.	74.	74.	74.	74.
	2	65.	53.	53.	53.	53.	53.	53.	53.	53.	53.
	3	49.	43.	43.	43.	43.	43.	43.	43.	43.	43.
	4	40.	37.	37.	37.	37.	37.	37.	37.	37.	37.
	5	35.	34.	34.	34.	34.	34.	34.	34.	34.	34.
20	1	216.	130.	110.	104.	103.	104.	104.	104.	104.	104.
	2	116.	79.	74.	74.	74.	74.	74.	74.	74.	74.
	3	82.	62.	60.	61.	61.	61.	61.	61.	61.	61.
	4	65.	53.	53.	53.	53.	53.	53.	53.	53.	53.
	5	55.	47.	47.	47.	47.	47.	47.	47.	47.	47.
30	1	316.	180.	144.	131.	127.	126.	127.	127.	127.	127.
	2	166.	105.	92.	90.	90.	90.	90.	90.	90.	90.
	3	116.	79.	74.	74.	74.	74.	74.	74.	74.	74.
	4	91.	66.	64.	64.	64.	64.	64.	64.	64.	64.
	5	76.	58.	58.	58.	58.	58.	58.	58.	58.	58.
40	1	416.	230.	178.	157.	149.	146.	145.	146.	146.	146.
	2	216.	130.	110.	104.	103.	104.	104.	104.	104.	104.
	3	149.	96.	86.	85.	85.	85.	85.	85.	85.	85.
	4	116.	79.	74.	74.	74.	74.	74.	74.	74.	74.
	5	96.	69.	66.	66.	66.	66.	66.	66.	66.	66.
50	1	516.	281.	211.	183.	170.	164.	162.	162.	163.	163.
	2	266.	155.	127.	118.	116.	116.	116.	116.	116.	116.
	3	182.	113.	98.	95.	95.	95.	95.	95.	95.	95.
	4	141.	92.	83.	82.	82.	82.	82.	82.	82.	82.
	5	116.	79.	74.	74.	74.	74.	74.	74.	74.	74.
60	1	616.	331.	245.	208.	191.	182.	179.	177.	177.	178.
	2	316.	180.	144.	131.	127.	126.	127.	127.	127.	127.
	3	216.	130.	110.	104.	103.	104.	104.	104.	104.	104.
	4	166.	105.	92.	90.	90.	90.	90.	90.	90.	90.
	5	136.	90.	81.	80.	81.	81.	81.	81.	81.	81.
70	1	716.	381.	278.	233.	211.	200.	198.	192.	191.	191.
	2	366.	205.	161.	144.	138.	136.	136.	136.	136.	136.
	3	249.	147.	121.	113.	112.	112.	112.	112.	112.	112.
	4	191.	117.	101.	97.	97.	97.	97.	97.	97.	97.
	5	156.	100.	89.	87.	87.	87.	87.	87.	87.	87.
80	1	816.	431.	312.	259.	232.	217.	210.	206.	204.	204.
	2	416.	230.	178.	157.	149.	146.	145.	146.	146.	146.
	3	282.	164.	133.	122.	119.	119.	119.	119.	119.	119.
	4	216.	130.	110.	104.	103.	104.	104.	104.	104.	104.
	5	176.	110.	96.	93.	93.	93.	93.	93.	93.	93.
90	1	916.	481.	345.	284.	252.	234.	225.	220.	217.	216.
	2	466.	256.	194.	170.	159.	155.	154.	154.	154.	154.
	3	316.	180.	144.	131.	127.	126.	127.	127.	127.	127.
	4	241.	143.	118.	111.	110.	110.	110.	110.	110.	110.
	5	196.	120.	103.	99.	98.	99.	99.	99.	99.	99.
100	1	1016.	531.	378.	309.	272.	251.	240.	233.	230.	228.
	2	516.	281.	211.	183.	170.	164.	162.	162.	163.	163.
	3	349.	197.	155.	140.	136.	133.	133.	133.	133.	133.
	4	266.	155.	127.	118.	116.	116.	116.	116.	116.	116.
	5	216.	130.	110.	104.	103.	104.	104.	104.	104.	104.

with a mixing height of 100 m, a windspeed of 1 m/sec, and a travel distance of 90 km, the areal averaged normalized concentration is found to be 474 sec/m. Multiplying this by the emission rate yields:

$$(474) \times (5.15 \times 10^{-3}) = 2.4 \text{ mg/m}^3 \text{ of CO}$$

Multiplying by 3/2 to account for the nonuniformity in traffic gives a final 1970 value of 3.6 mg/m^3. Applying a 1970 to 1975 average emission rate correction factor of 0.7, the average background is 2.5 mg/m^3.

As a second example, the Washington, D.C. AQCR (National Capital) encompasses an area of 5,964 km^2 and had CO emissions estimated at 232.72 ton/yr/km^2 in 1970. Assuming the AQCR to be roughly circular, the travel distance is again about 90 km. Using Table 15, $\overline{\chi}/\overline{Q}$ is 481 sec/m, assuming a 100 m mixing height and a 1 m/sec windspeed. Making the appropriate correction, the emission rate is:

$$(232.72) \times (2.88 \times 10^{-5}) \times (3/2) = 1.01 \times 10^{-2} \text{ mg/m}^2 \text{ sec}$$

The average background concentration is then:

$$(1.01 \times 10^{-2}) \times 481 = 4.9 \text{ mg/m}^3$$

for 1970, or

$$(4.9 \text{ mg/m}^3)(0.7) = 3.4 \text{ mg/m}^3$$

for 1975.

C. EVALUATION TECHNIQUES FOR DETERMINING THE FREQUENCY OF EXCEEDING NAAQS

The problem of determining the frequency of standards exceedance is basically one of finding how often the requisite traffic and meteorological conditions that lead to a violation of the NAAQS occur jointly. The carbon monoxide concentration, χ, at a hot spot location is a function of the wind-roadway angle, θ, the windspeed, u, the atmospheric stability class, S, the initial vertical dispersion parameter, σ_{zo}, the traffic conditions leading to a line source emission rate, Q, and the road-receptor distance, x:

$$\chi = f\ (\theta,\ u,\ S,\ \sigma_{zo},\ Q,\ x)$$

Values of these parameters fall in the ranges:

$0^{o} \leq \theta \leq 90^{o}$
$0 < u$
$S''' \leq S \leq S''$ assuming some continuous measure of stability
$1.5\text{m} \leq \sigma_{zo} \leq 5\text{m}$

$0 \leq Q \leq Q''$, where Q'' is the maximum possible line source emission rate for the roadway

and

$0 < x.$

As noted, not all combinations of values of these parameters will lead to a violation of the standards. Furthermore, there are values of the individual parameters for which a standard violation could not occur, no matter what values the other parameters take. For example, a 1-hour standard violation would certainly not occur with a windspeed, u, of 10 m/sec. Denoting these critical values of the parameters with primes, the values leading to standards violations fall in the ranges:

$0 \leq \theta \leq \theta' \leq 90^{0}$
$0 < u \leq u'$
$S''' \leq S' \leq S \leq S''$ assuming some continuous measure of stability with S''' being least stable and S'' being most stable
$1.5\text{m} \leq \sigma_{zo} \leq \sigma_{zo}' \leq 5\text{m}$
$0 \leq Q' \leq Q \leq Q''$

and

$0 < x \leq x''$

If the joint frequency function of concentration values $f(\chi) = f(\theta, u, S, \sigma_{zo}, Q, x)$ is known, then the probability of a violation of a standard is given by:

$$\int_{o}^{x'} \int_{Q'}^{Q''} \int_{1.5}^{\sigma'_{zo}} \int_{S'}^{S''} \int_{o}^{u'} \int_{o}^{\theta'} f(\theta,u,S,\sigma_{zo},Q,x)\, d\theta du dS d\sigma_{zo} dQ dx.$$

Finding such a joint frequency function would, of course, be extremely difficult in practice. If the variables were independent, one could possibly find the frequency function of each variable and then find the product of the integrals of the functions of each variable. However, they are not independent; stability and the initial vertical dispersion parameter are both functions of windspeed, for example. Stability is not, in practice, a continuous parameter but rather is separated into discrete classes. Additionally, variations in other parameters can tend to move together; for example, windspeed and emission rates are both likely to be lower at night and higher during the day. Hence, for application, the method of determining the frequency of violation of the standards requires simplifying assumptions.

As a start, the road-receptor separation at a given hot spot location will generally be some given, fixed value. According to the Indirect Source Guidelines, the value of the initial vertical dispersion parameter is 5 m in urban locations, and 5 m in suburban locations unless the line source is removed from neighboring buildings by at least 10 times the building height. In this case, σ_{zo} equals 1.5 m. Also, only stability classes D and E are considered as possibly leading to a violation of the NAAQS. Thus, x is fixed, S may take on two discrete values, and σ_{zo} may have one value for urban areas and two discrete values for suburban areas, but only one of these values will pertain to a particular location. Since the frequency of occurrence of the fixed values of x and $\sigma_{zo} = 1$, independent of the other variables, the joint frequency function can be rewritten for the remaining variables only:

$$F(\chi) = f\ (\theta,\ u,\ S,\ Q)$$

From this point, an analysis can be made of historical meteorological data to find how frequently different values of θ, u, and S occur. To start with, an objective scheme can be used to determine how often D and E stability classes occur. Then, for times when these stability classes do occur, the distributions of θ and u can be found. Since θ and u are not really independent, the frequency ideally would be generated in terms of the joint occurrence of a windspeed and a wind angle during periods of atmospheric stability class D and periods of atmospheric stability class E.

Though not totally accurate, it is reasonable to assume that the traffic conditions leading to different emission rates, Q, are independent of the meteorological parameters. In general, traffic at a given location varies with time of day and day of week (weekday, Saturday, and Sunday). The frequency of values of Q can then be generated by time of day for weekdays, Saturdays, and Sundays. This implies that the meteorological data frequencies should also be known by time of day. At this point, it is possible to say how often each stability class occurs, and that during the occurrence of each stability class, a certain windspeed and wind angle occur at a given time of day with known frequency.

Knowing the combinations of u, θ, S, and Q that lead to a violation of the standards, it is now possible to say how frequently, during some time period such as a year, the standards are likely to be violated.

An additional confounding factor should be discussed here. This involves the line source emission rate, Q. At intersections, the line source emission rate (and the peak carbon monoxide concentration) depends on the type of control at the intersection, volume on the cross street, queue length, and delay, as well as on the volume of traffic on the street under consideration. In practice, it would be extremely difficult to determine the influence of all these factors on the emission rate, carbon monoxide concentrations, and the frequency with which variations in these factors occur. This problem does not exist for free flow sections of a roadway where emissions depend on the traffic volume (and speed) on that roadway only. At the intersection, the interaction of queue length and wind angle on concentrations make it impossible to use a single range of wind angles in considering conditions leading to violations of the NAAQS. Different ranges of wind angles are important for different queue lengths, that is, for different spatial variations in Q. To simplify this problem, the assumption could be made that the emission rate is constant along the line source irrespective of the actual changes that do occur along an approach owing to variable operating characteristics (queuing, accelerating, etc.).

With the above assumption, it is possible to get an idea of how frequently the NAAQS are likely to be violated at a hot spot location. The only remaining information needed pertains to the values of the parameters that lead to violations. Figure 43 can be used to help determine these values. Figure 43 shows curves of constant Q as a function of wind-road angle on the ordinate and windspeed on the abscissa. These values of Q will lead to a 1-hour average concentration of approximately 14.3 mg/m^3 for stability class D, a road-receptor distance of 10 m, and initial vertical dispersion of 5 m. Applying the persistence factor of 0.7 (discussed previously) to the 14.3 mg/m^3 hourly concentrations results in an estimated 8-hour average concentration of 10 mg/m^3. Figure 43, then, actually shows wind-road angle, wind speed and emissions rate combinations that result in potential violations to the 8-hour standard (10 mg/m^3) for CO.

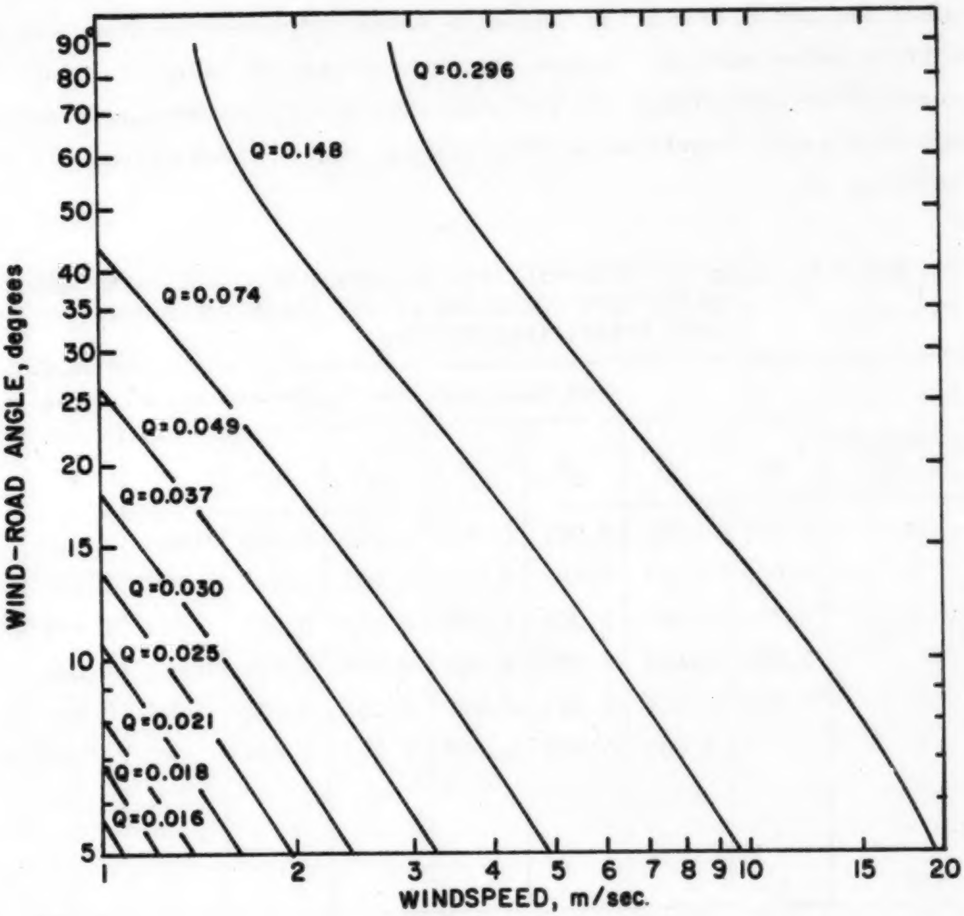

Figure 43. Lines of constant emission rate yielding violations of the 8-hr CO standard as a function of windspeed and wind angle

Example

An example problem may be helpful at this point. For this example, consider the School Street at Lexington Street intersection discussed in the verification section. Assume that an analysis of historical data resulted in identifying the probabilities of certain average windspeed and wind angle (expressed as wind/roadway angle) combinations, as shown in Table 16.

Table 16. ASSUMED PROBABILITIES OF HOURLY WINDSPEED/WIND ANGLE COMBINATIONS OCCURRING AT THE LEXINGTON STREET - SCHOOL STREET INTERSECTION

Windspeed (m/sec)	Wind direction (as wind-road angle)								
	0°	1°	2°	3°	4°	5°	6°	7°	8° ... etc.
1	0.000	0.002	0.001	0.002	0.003	0.008	0.006	0.003	0.004
2	0.000	0.003	0.002	0.000	0.001	0.005	0.004	0.002	0.006
3	0.001	0.001	0.002	0.000	0.002	0.003	0.002	0.001	0.002
4	0.001	0.001	0.001	0.003	0.003	0.002	0.001	0.003	0.001
5	0.004	0.004	0.003	0.003	0.002	0.004	0.003	0.006	0.003
6		0.002	0.004	0.005	0.003	0.004	0.003	0.004	0.005
"									
"									
etc.									

Assume further that the probability of stability class D occurring during the peak hours is 1.000.

From the verification computations shown in Figure 41, it can be seen that the maximum 1-hour average concentration from vehicle emissions at the intersection is 16.1 mg/m^3. Referring to Figure 33, the normalized concentration from free-flow emissions is 870×10^{-3} m^{-1} at 10 meters. The free-flow emission rate, Q, is equal to the receptor concentration, 16.1 mg/m^3, divided by the normalized concentration from free flowing traffic, 870×10^{-3} m^{-1}, which equals 0.0185 gm/m sec. Figure 43 shows the combinations of windspeed and wind/road angle for various emission rates that would result in a 1-hour average concentration of 14.3 mg/m^3, which, in turn, would violate the 8-hour standard (again, applying the persistence factor of 0.7 to 14.3 yields of 10.0 mg/m^3). From Figure 43, it can be seen that, when Q has a value of 0.0185, the 8-hour CO standard will be violated only when the windspeed and direction (relative to the axis of the road) are 1 meter per second and 5° to 7°, respectively. Looking at Table 16 it can be seen that the probabilities of windspeed-wind direction combinations of 1 meter per second and 5°, 1 meter per second at 6°, and 1 meter per second at 7°, are 0.008, 0.006 and 0.003, respectively.

The probability of these combinations of conditions occurring on an annual basis can be computed as:

$$P = (\frac{5}{7})\ (\frac{1}{24})\ (0.008 + 0.006 + 0.003) = 0.00051$$

where $\frac{5}{7}$ accounts for the assumption that the Q value used reflects workday traffic emissions and that the Q value for weekend traffic would be significantly lower; and

$\frac{1}{24}$ accounts for the assumption that the Q value used is the maximum value for the day/ hence, occurs only once in 24 hours.

The number of times that the 8-hour standard is likely to be exceeded is:

$$(0.00051)(365\ \text{day/year})(24\ \text{hour/day}) \approx 4\ \text{times per year}$$

Additionally, one would also have to consider the hourly traffic patterns that would yield emissions rates of from 0.016 to 0.0185 (these would possibly occur during hours other than peak hours), and compute the probabilities in the same manner as for the peak hour shown above. This actually would indicate the number of hours during the year when emissions rates are at least 0.0016 (which, according to Figure 43 is the threshold emission rate) and the appropriate windspeed and direction parameters are coincidental (hence, 8-hour average CO concentrations are likely to be 10 mg/m^3, or greater). What this would not indicate, however, are the number of nonoverlapping 8-hour averaging periods occurring annually; rather, all 8-hour averaging periods would be indicated.

SECTION VI

APPLICATIONS OF THE HOT SPOT GUIDELINES

A. PLANNING OR EVALUATION OF LOCATIONS FOR AMBIENT CO MONITORING

1. Introduction

The guidelines presented here can be used to assess the degree to which ambient CO monitoring instruments are representative of the CO concentrations at hot spots. This discussion provides suggestions for how to use these guidelines to evaluate either present or possible future locations as to their suitability for CO monitors.

This discussion should be considered as a supplement to the other EPA guidance on placement of air quality monitors. In particular, placement of CO monitors should be in accordance with:

- Guidance for Air Quality Monitoring Network Design and Instrument Siting (Revised). OAQPS Number 1.2-012. July 1975. Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C., (hereinafter referred to as OAQPS 1.2-012).[12]
- CO Siting. Supplement A to OAQPS 1.2-012. Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C., (hereinafter referred to as Supplement A).[13]

The present discussion is intended to aid in the review of alternative monitoring locations from the standpoint of their suitability for various types of monitoring objectives. However, to decide if a monitor should be at one intersection or another, or near one highway or another, or to evaluate the exact physical location such as side of street, height of probe, or lateral placement from curb, these guidelines should be used together with OAQPS 1.2-012 and Supplement A.

In using these guidelines to review CO monitor placement, it is important to keep certain key points in mind:

- These guidelines provide an estimate of the maximum CO concentration likely to occur near the location in question. The calculated CO level may not be the very highest that could ever occur, but can reasonably be expected to be representative of the highest several periods in the year.

- These guidelines do not indicate exactly where in the vicinity of an intersection or midlock location that the peak CO level will occur; the analysis assumes a standard, conservative wind direction which may not coincide with actual prevailing winds. Thus, there is little or no physical meaning to the association of each leg of an intersection with a particular CO level. That is, the verification estimate procedure produces a series of CO level estimates, the highest of which is representative of the potential for CO concentrations near that location..

- In contrast to what the guidelines indicate, actual peak CO level will tend to occur in an area downwind from a hot spot, the exact location depending upon wind direction and speed, building arrangement, topography, and location of other CO sources.

- Thus, air quality monitors will measure the CO levels at only one particular location near a hot spot, but may not identify the maximum CO concentration. The screening guidelines will estimate the maximum CO concentration but will not show where it occurs. The relationship between the two will therefore depend on the details of local circumstances.

2. Overall Procedure

In order to use this document for evaluating either existing or future monitor locations, it is recommended that the following sequence of steps be followed. The sequence of steps is also portrayed in Figure 44.

1. Identify the type of site in question. OAQPS 1.2-012 and Supplement A define several types of CO monitor sites. Which type is intended depends upon the ultimate use of the data, and upon the overall network design. The types of monitors that are defined in OAQPS 1.2-012 are:
   - Street Canyon
     - Peak
     - Average
   - Neighborhood
     - Peak
     - Average
   - Corridor
   - Background
2. Determine whether the physical characteristics of the site are suitable for the intended purpose of the monitoring site. Supplement A discusses microscale questions such as probe height, exposure to prevailing winds, and other issues that must be resolved independently of the question of hot spots.
3. Determine how estimated CO levels for the site(s) in question compare with those at other locations in the area. At this point one would use information from the CO hot spot screening procedure to determine whether a particular site is likely to be among those with the highest CO levels, lowest levels, and so on. This will be discussed in more detail below.
4. Determine whether the site in question satisfies the requirements for the particular monitor type. Using information from both steps 2 and 3, one can tell if a particular monitor location is appropriate, and if not, how well it satisfies the criteria for one or another monitoring type.

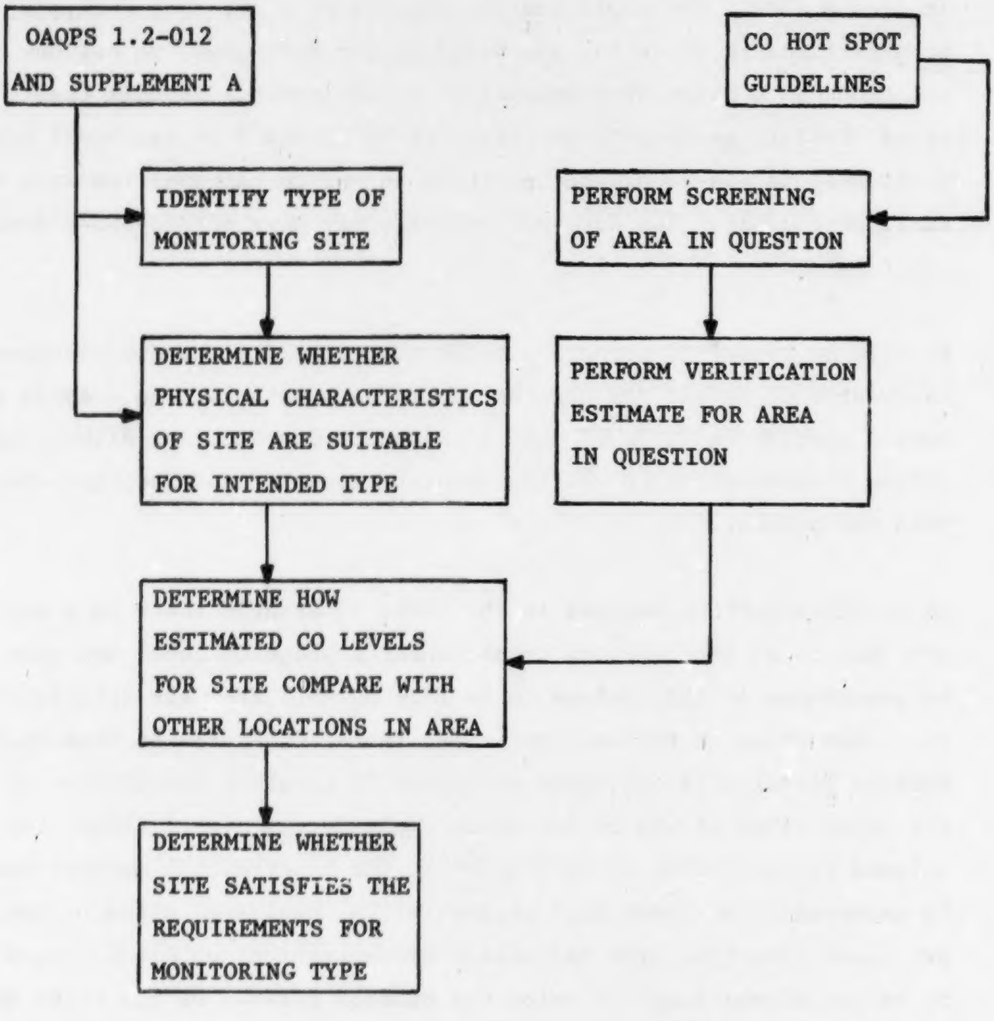
OAQPS 1.2-012
AND SUPPLEMENT A
CO HOT SPOT
GUIDELINES
IDENTIFY TYPE OF
MONITORING SITE
PERFORM SCREENING
OF AREA IN QUESTION
DETERMINE WHETHER
PHYSICAL CHARACTERISTICS
OF SITE ARE SUITABLE
FOR INTENDED TYPE
PERFORM VERIFICATION
ESTIMATE FOR AREA
IN QUESTION
DETERMINE HOW
ESTIMATED CO LEVELS
FOR SITE COMPARE WITH
OTHER LOCATIONS IN AREA
DETERMINE WHETHER
SITE SATISFIES THE
REQUIREMENTS FOR
MONITORING TYPE

Figure 44. Block diagram of process to review monitoring locations

3. Use of Hot Spot Analysis

In Step 3 above, one would use the results of a hot spot analysis, including both preliminary screening and verification estimates, to see how various locations in a given area compare as to CO levels. In this case, "area" means whatever geographic territory it is intended to represent with the monitor(s) in question, whether it is an entire metropolitan area or some small part of it. The hot spot analysis may have already been done for other reasons.

It will be useful to prepare a table that displays the distribution of calculated CO levels for all the evaluated locations. An example of such a display is Table 17. This frequency distribution allows one to obtain a perspective on the representativeness of one location compared with the others.

As an illustration, suppose in the Table 17 example there is a monitor adjacent to an intersection whose 8-hour average CO level has been estimated by procedures in this volume to be 19.4 mg/m^3. From the tabulation of data for other sites in the same vicinity, Table 17, it can be seen that the monitor location is one whose estimated CO level is exceeded by at least six other sites of the 51 for which analysis was done.* Thus, the calculated concentration of 19.4 mg/m^3 at the hypothetical monitor location is exceeded by at least 11.7 percent of the evaluated sites. Also, there are seven locations with calculated concentrations within 2.0 mg/m^3 (above or below) of the range in which the monitor falls. On the other hand, the calculated level exceeds the levels for 43 of those locations that were evaluated, and presumably exceeds the levels for all locations that were not screened because of their obvious low potential as hot spots.

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*Note that the monitor itself may provide CO readings considerable less than that calculated for the adjacent intersection, depending upon the monitor's location relative to the potential hot spot (height, lateral separation, leeward versus windward side, etc.). Such microscale details must be considered but are separate from the overall locational issues being addressed here.

Table 17. HYPOTHETICAL EXAMPLE TABULATION OF CALCULATED CO LEVELS

Range of estimated 8-hr average CO concentration, mg/m^3	Number of locations in range	Number of locations in or above the range
<9	21	51
9.0 – 10.9	5	30
11.0 – 12.9	5	25
13.0 – 14.9	5	20
15.0 – 16.9	4	15
17.0 – 18.9	3	11
19.0 – 20.9	2	8
21.0 – 22.9	2	6
23.0 – 24.9	2	4
25.0 – 26.9	1	2
27.0 – 28.9	1	1
>29.0	0	0

Having compared the CO concentrations estimated for various locations, one would next determine whether the site in question satisfies the requirements for a monitor of the type involved (Step 4). For this determination, it is necessary to consider both the physical characteristics of the site - evaluated in Step 2 but not discussed in detail here - and the CO characteristics as shown by Step 4.

Following the example given here, suppose that the hypothetical monitor location being discussed is intended to be a "peak station" in the sense used in OAQPS 1.2-012 and Supplement A. The OAQPS guidelines say that peak stations are to be representative of a number of similarly highly congested locations. How well does the hypothetical location satisfy this criterion?

In Step 3, we saw that there are six locations calculated to have CO concentrations of more than 21.0 mg/m^3, out of 51 locations evaluated. Thus, the calculated concentration of 19.4 mg/m^3 at the hypothetical monitor location is indicative of several locations but is not the worst potential hot spot. Tentatively, it would be reasonable to conclude that the monitor is a suitable location for a peak station. This tentative conclusion must be confirmed by also examining the type of locations involved, and the details of the monitor's placement. Supplement A recommends several considerations, and also refers to a report that discusses issues such as wind direction relative to street orientation, use of a dispersion model for evaluations, and other details.[14]

One factor of concern to microscale location of monitors, namely, lateral separation from the intersection, can be examined in part with these hot spot guidelines. The effect of lateral separation is demonstrated by Figures 36 and 37. These graphs should be used to estimate the ratio between the maximum CO concentration likely within the vicinity of the hot spot (as calculated with these guidelines) and the CO levels measured by the monitor. This ratio is only an estimate because these guidelines do not allow for determination of specific wind direction effects. Such effects will affect actual monitor readings and should be considered in monitor placement (and data interpretation) as described in the OAQPS 1.2-012 guidelines.

As an example, using our hypothetical location, suppose that the monitoring instrument inlet is 25 meters from the centerline of the roadway. Suppose further that a midblock location is involved. Using Figure 37, the distance of 25 meters corresponds to a correction factor of about 0.55. Thus, the calculated level of 19.4 mg/m^3 would be estimated as $(0.55) \times (19.4) =$, 10.7 mg/m^3 at the monitor inlet. (If the monitor inlet were adjacent to an intersection, this adjustment should be performed for both nearest intersection legs, and the higher value used.) This distance correction allows for approximate correlation of measured and calculated CO concentrations. In this connection, it is apparent that a monitoring instrument that is intended to measure peak CO levels should be rather close to the street, consistent with being a reasonable receptor site.

B. EVALUATING AREAWIDE CONTROL MEASURES

While the hot spot screening and verification procedures are designed primarily for the rapid identification and substantiation of localized carbon monoxide hot spots, they may also serve as a primary input to the planning and evaluation of areawide measures to obviate hot spots. In particular, this section discusses how to use the guidelines to evaluate the effects of the Federal Motor Vehicle Emission Control Program (FMVECP), inspection and maintenance programs (I/M), and retrofit programs. The types of questions that might be answered by the following evaluation methods include:

- If there are X hot spots in year Y, how many will there be in year Z due to the effects of the FMVECP?
- If there are currently X hot spots, how many will be eliminated by the planned I/M criteria?
- To eliminate Y out of X hot spots, what must the I/M criteria be?
- How many hot spots will be eliminated by the implementation of a retrofit program?

Questions involving the effects of traffic flow or traffic volume changes require only a straightforward reapplication of the procedures and are not discussed here. Additionally, these measures have localized effects (with the exception of measures like shifts to mass transit or carpools) and are not relevant to the discussion of areawide measures.

The following methods assume that the verification procedures have been carried out.

1. Effects of the FMVECP

The effects of the FMVECP are included in Table 12. The capability for applying the verification procedure for any year from 1978 through 1990 is provided in the emission correction factors provided in Table 12. Local vehicle mix data must be included as in the verification techniques described previously. Only then can Table 12 be used properly to identify the effects of FMVECP.

2. Effects of I/M

Three methods are available for considering the effects of an I/M program.

The first method, which is preferred and most accurate, is to use the computer programs described in Carbon Monoxide Hot Spot Guidelines, Volume IV: Documentation of Computer Programs to Generate Volume I Curves and Tables.[4] These programs were used to generate the screening curves and tables of correction factors and excess emission rates presented in this document. The programs are capable of calculating screening curves, tables of excess and cruise emissions, and emission correction factors that assume the implementation of a specific I/M program. They are also capable of calculating tables and curves that are specific to a certain region's vehicle age and travel distribution, vehicle mix, etc.

The second method is to calculate the excess and cruise emission rates by hand using the same methodology as that employed in the program. The methodology is described in Volume II of these guidelines. Since it could easily take a day to calculate by hand the excess and cruise emission rates for one verification analysis, this is an appropriate method if only one analysis is being done or if the speeds, temperatures, cold and hot starts, and calendar years do not vary among several verification analyses. Considering the number of calculations involved, it is subject to some error.

A third possibility is to apply a correction factor to the composite excess emission rates and cruise emission rates. This is definitely an inaccurate procedure and is not recommended. One may wish to employ it to obtain an approximation before proceeding with a more detailed calculation, however. The procedure for doing so is to first calcualte the FTP composite emission factor and the idle emission factor for scenario (i.e., year, cold starts, speed, etc.) of interest without implementation of I/M. Call these factors E_{FTP} and E_{IDLE}. Next, calculate the emission factors for the same scenario with the implementation of I/M. Call these values E^{IM}_{FTP} and E^{IM}_{IDLE}. In verification procedure adjust the excess and cruise emission rates, Q_E and Qf_i, as follows:

$$Q_{fi}' = Q_{fi} \frac{E^{IM}_{FTP}}{E_{FTP}}$$

$$Q_e' = \left(Q_{fi} + Q_e\right) \frac{E^{IM}_{IDLE}}{E_{IDLE}} - Q_{fi}'$$

Enter Qf_i' and Q_e' on lines 9 and 16 instead of Qf_i and Q_e.

3. Effects of a Retrofit Program

The effects of a retrofit program will be similar to those of I/M, except that only early model year vehicles will be affected. There is no guidance in AP-42 regarding allowances. Once reasonable allowances are derived from the design of the program the procedure used for I/M may be applied to determine the effects on the number of potential hot spots.

SECTION VII

EVALUATION OF THE HOT SPOT GUIDELINES

A. INTRODUCTION

This section summarizes an evaluation of the procedures presented in the Hot Spot Guidelines and presents illustrations of the application of the guidelines procedures. The evaluation is meant to determine, by way of comparing guideline procedure results with measured CO concentrations, whether the guidelines serve their intended purpose; that is, whether they identify potential hot spots.

It should be noted that an extremely detailed validation study is virtually impossible using existing monitoring data from either permanent or temporary stations. The guidelines procedures assume a receptor location that depends on traffic volumes, traffic signal parameters, traffic flow parameters, and physical characteristic of the roadway. For a given set of these parameters, a critical wind angle leading to maximum concentrations is also assumed. A discussion of these relationships is provided in Sections II and III of this report. Thus, a highly specialized, mobile monitoring program would be required to collect data for validation of these guidelines. The purpose of this evaluation is to ensure that the guidelines procedures are sufficiently conservative. They should detect and verify all potential hot spots and, if they err, they should err towards defining a location as a potential hot spot even though it might be only marginally so. In this regard, the verification procedure concentration estimates should generally always be at least as high as observed values.

Since the screening procedure is based totally on the verification procedure, there is no need to provide separate assessments of each; if it is shown that the technical aspects of the verification process are sound, then it would be valid to assume that the technical basis for the screening techniques is also sound. In this connection, then, an assessment was made only of the validity of the verification procedure. It should be pointed out again that the technical basis for the entire procedure is the EPA Indirect Source Guidelines,[16] which has been evaluated[15] already. In this sense, it can be considered that the technical basis for the Hot Spot Guidelines has also been assessed.

B. EVALUATION OF THE VERIFICATION PROCEDURE

In order to evaluate the adequacy of the verification procedure as a tool for identifying the highest CO concentrations likely to occur at a location, a comparative analysis was performed that considered actual measured air quality data and estimates derived using the hot spot guidelines. Comparisons were made of the highest measured CO concentrations, and the maximum value computed using the verification procedure for several signalized intersections and for several sections of roadway with uninterrupted flow. These are discussed below.

1. Case I: Verification at Signalized Intersections

The data required for the verification of six signalized intersections were collected and compiled. The major constraint with regard to selecting study sites was the availability of representative, measured CO data. The data for three of the sites analyzed were obtained from specific short-term studies designed to evaluate local carbon monoxide levels. As a result, the associated CO monitoring activities ranged from a few days to a few weeks. The three remaining sites were selected because of the existence of continuous monitoring programs at the sites and because of the availability, at the minimum, of a full year's CO concentration data.

Before presenting the verification results of the signalized intersections, two caveats that affect the evaluation are highlighted. The first concerns the location of the CO monitors. The verification procedure is designed to predict CO concentrations at receptor sites where the maximum projected level is most likely to occur. The locations where these maximum concentrations occur depend on meteorological factors, such as windspeed and direction, and traffic characteristics, such as queue length. The actual air quality monitors, however, are not located at the point where, under the conditions assumed in the verification process, the maximum concentrations occur. Therefore, the validation procedure should not be expected to show close agreement between the maximum estimated and measured concentrations; rather, the validation should show that in all instances, the estimated values are higher than the measured concentrations.

The second caveat concerns the probability that the CO concentrations recorded are representative of the potential maximum concentrations. The CO concentration data for three of the intersections were obtained from rather short-term monitoring programs where sampling periods ranged from a few days to a few weeks. It is highly unlikely that maximum CO levels were recorded because of the shortness of the monitoring period and because of seasonal implications of not necessarily monitoring during a "critical" season (i.e., winter).

Table 18 presents the observed data along with the estimated values of the verification procedures. At the three sites listed in Table 18 where long-term monitoring data were available, the estimated values indicate potential violations of the NAAQS. The observed concentrations verify the fact that violations of the NAAQS did occur. In all three cases the calculated value is greater than the maximum observed concentrations. Again, monitor location plays a major role in these differences.

Of the other three locations, only two recorded violations in the NAAQS. This is compared to results of the verification, which indicated maximum values in excess of the NAAQS at all three locations. In all cases the

Table 18. CASE I: RESULTS OF THE VERIFICATION PROCEDURE AT SIGNALIZED INTERSECTIONS

Location	City	Monitor site[a]	8-hour average CO concentration (ppm)			
			Estimated	Year	Observed	Date
Buckingham St. at Washington St.	Hartford, Conn.	Trailer - (P) at State Office Bldg.	35.1	1974	21.2	6/23/74
Colfax Ave. at Colorado Blvd.	Denver, Colo.	National Jewish Hospital - (P)	55.8	1974	19.7	11/21/74
Moody St. at Carter St.	Waltham, Mass.	Trailer - (P)	24.3	1975	19.9	1/25/75
Wisconsin Ave. at Western Ave.	Washington, D.C.	Trailer - (T)	51.7	1974	13.9	5/03/74
MacArthur Blvd. at South Grand Ave.	Springfield, Ill.	Site A - (T)	27.6	1975	5.5	12/05/75
		Site B - (T)	22.7	1975	2.9	12/05/75
		Site C - (T)	18.6	1975	2.6	12/05/75
		Site D - (T)	26.1	1975	2.3	12/05/75
Illinois Rte. 83 at Twenty-Second St.	Oak Brook, Ill.	Station No. 13 - (T)		1975	8.2	4/05/74

[a] (P) indicates permanent CO monitoring site; (T) indicates temporary CO monitoring site.

verification results are considerably greater than the maximum observed concentrations from the short-term monitoring programs, as might be expected.

2. Case II: Verification at Uninterrupted Flow Locations

Table 19 presents the results of the application of the verification procedures at two major arterials in western New York State and one arterial in Colorado. The maximum 8-hour average CO concentration observed at either New York site during a 6-month air quality study, August 1975 through January 1976, was 6.2 ppm. These levels were recorded during 28 October 1975 for the Buffalo location and 30 December 1975 for the Niagara Falls site. Applying the verification procedures results in estimated levels of 9.8 ppm and 5.7 ppm for Buffalo and Niagara Falls, respectively. The Colorado site also shows hot spot potential with an estimated maximum 8-hour average concentration of 12.5 ppm.

3. Case III: Comparison with Hourly Data at a Single Intersection

Hourly data were collected during a carbon monoxide and traffic monitoring program conducted at the Oakbrook Shopping Center in Oakbrook, Illinois.[25] A major intersection, Illinois Route 83 and Twenty-Second Street, southwest of the center, was monitored as part of the shopping center study. An evaluation of the hot spot verification guidelines presented in this report has been conducted using the data collected at this signalized intersection in Oakbrook. These data were also used to evaluate the Indirect Source Guidelines.[15]

Twenty sets of observed and estimated 1-hour average CO concentrations were analyzed; these data represent 11 different hourly periods and four different CO monitors. Table 20 summarizes the observed CO concentrations along with the estimated concentrations of the verification procedures. The estimated values are greater in all cases, as expected, because the hot spot verification procedures are designed specifically to estimate

Table 19. CASE II: RESULTS OF THE VERIFICATION PROCEDURE AT UNINTERRUPTED FLOW LOCATIONS

Location	City	Monitor site	8-hour average CO concentration (ppm)			
			Estimated	Year	Observed	Date
Sheridan Dr. Rte. 324 west of Ellicott Creek	Buffalo, N.Y.	Trailer - (T)	9.8	1975	6.2	10/28/75
Military Rd. Rte. 265 at LaSalle High School	Niagara Falls, N.Y.	Trailer - (T_	5.7	1975	6.2	12/30/75
West 57th Ave.	Arvada, Colo.	Trailer - (P)	12.5	1975	11.6	11/21/74

Table 20. OBSERVED VERSUS ESTIMATED 1 HOUR CO CONCENTRATIONS, AT INTERSECTION OF ILLINOIS ROUTE 83 AND TWENTY-SECOND STREET, OAKBROOK, ILLINOIS

Date	Hour	Receptor	CO concentration 1 hour average - (ppm)		
			Observed	Estimated	Estimated with windspeed correction
4/05/74	18	162	7.3	19.3	6.2
3/28/74	10	162	5.6	16.6	7.6
3/29/74	10	162	7.3	18.3	8.3
3/26/74	17	162	7.0	18.2	5.9
4/02/74	08	14	7.3	13.7	5.1
4/13/74	14	14	3.0	18.3	4.0
4/13/74	15	14	3.0	20.1	4.4
4/02/74	08	15	3.9	17.6	6.4
4/13/74	16	15	3.9	31.1	7.8
4/13/74	14	15	5.6	31.6	7.0
4/13/74	15	15	5.6	33.3	7.4
4/09/74	18	15	8.2	29.7	8.2
4/06/74	13	15	4.7	26.3	6.6
4/06/74	11	15	4.7	26.9	6.0
4/02/74	08	13	7.3	13.3	5.0
4/13/74	16	13	4.7	19.7	5.0
4/13/74	14	13	3.9	22.1	4.9
4/13/74	15	13	4.7	21.1	4.7
4/09/74	18	13	4.7	23.6	6.6
4/06/74	13	13	4.7	18.7	4.7

the CO concentration potential under worst case conditions. If the estimated values are corrected for windspeed (a windspeed of 1 m/sec is assumed for Hot Spot Analysis), the agreement between measured and estimated values improves considerably.

C. CONCLUSION

The hot spot screening and verification procedures have been evaluated on the basis of comparisons with CO measurements. This section has demonstrated the reasonableness of the guidelines as to their intended purpose, which is to serve as a tool to facilitate an efficient review of potential CO hot spot conditions along existing roadway networks. Comparisons with observed CO levels at seven signalized intersections and with observed and estimated values for different times at a single intersection illustrate that the guidelines identified all potential hot spot locations analyzed.

SECTION VIII

REFERENCES

1. Frye, F. F. Alternative Multimodal Passenger Transportation Systems, Comparative Economic Analysis. Creighton Hamburg, Inc. For: Highway Research Board, Washington, D.C. National Cooperative Highway Research Program Report Number 146:68. 1973.

2. Benesh, F., and T. Midurski. Carbon Monoxide Hot Spot Guidelines Volume II: Rationale. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/3-78-034. August 1978.

3. Midurski, T. Carbon Monixide Hot Spot Guidelines Volume III: Workbook. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/3-78-035. August 1978.

4. Benesh, F. Carbon Monoxide Hot Spot Guidelines Volume IV: Documentation of Computer Programs to Generate Volume I Tables and Curves. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/3-78-036. August 1978.

5. Benesh, F. Carbon Monixide Hot Spot Guidelines Volume V: Users Manual for the Intersection-Midblock Model. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/3-78-037. August 1978.

6. Benesh, F. Carbon Monoxide Hot Spot Guidelines Volume VI: Users Manual for the Modified ESMAP Model. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/3-78-040. August 1978.

7. Kunselman, P., et al. Automobile Exhaust Modal Analysis Model. U.S. Environmental Protection Agency. Report No. EPA-460/3-74-005. January 1974.

8. U.S. Environmental Protection Agency. Mobile Source Emissions Factors for Low Altitude Areas. Final Document. EPA-400/9-78-086. March 1978.

9. Highway Capacity Manual. Highway Research Board, National Academy of Sciences, National Research Council, Washington, D.C. Special Report No. 87. 1965.

10. Transportation and Traffic Engineering Handbook. Institute of Traffic Engineers, Arlington, Virginia. 1976.

11. Robertson, J. E. The Impact of Vehicle Emissions on Air Quality at Low Ambient Temperatures. Society of Automotive Engineers. Paper No. 741054. (Presented at the Automobile Engineering Meeting. Toronto, Canada. October 1974.)

12. Guidelines for Air Quality Monitoring Network Design and Instrument Siting (Revised). U.S. Environmental Protection Agency Report No. OAQPS 1.2-012. Research Triangle Park, North Carolina 27711. July 1975.

13. CO Siting. Supplement A to OAQPS 1.2-012. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina 27711.

14. Ludwig, F. L., and J. H. S. Kealoha. Selecting Sites for Carbon Monoxide Monitoring. U.S. Environmental Protection Agency Report No. EPA-450/3-75-077. Research Triangle Park, North Carolina 27711. September 1975.

15. Rationale for an Evaluation of Technical Guidelines for the Review of Indirect Sources (Draft). Stanford Research Institute, Menlo Park, California. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. July 1976.

16. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9 (Revised): Evaluating Indirect Sources. OSQPS No. 1.2 -028R, EPA-450/4-78-001. U.S. Environmental Protection Agency, Research Triangel Park, North Carolina. September 1978.

17. Georgii, H. W., E. Busch, and E. Weber. Investigation of the Temporal and Spatial Distribution of the Emission Concentration of Carbon Monoxide in Frankfurt/Main, Reports of the Institute of Meteorology and Geophysics of the University of Frankfurt/Main. May 1967.

18. Midurski, T. P., and A. H. Castaline. Guidelines for Identification and Evaluation of Localized Violations of Carbon Monoxide Standards. Final Guideline Report. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Region I Office, Boston, Massachusetts. Publication Number EPA-901/9-76-001. January 1976.

19. Midurski, T. P., et al. Mobile Source CO Hot Spot Guidelines, Volume II: Rationale and Detailed Example. GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. December 1977.

20. Midurski, Theodore P. Determination of Percentages of Vehicles Operating in the Cold Start Mode. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-77-023. August 1977.

21. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9 Evaluating Indirect Sources. U.S. Environmental Protection Agency Report No. EPA-450/4-75-001. January 1975.

22. Holzworth, G. C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. U.S. Environmental Protection Agency Report No. AP-101, Office of Air Programs, Research Triangle Park, North Carolina 27711. January 1972.

23. The National Air Monitoring Program: Air Quality and Emissions Trends Annual Report. Volume II. U.S. Environmental Protection Agency Report No. EPA-450/1-73-001b. Research Triangle Park, North Carolina 27711. August 1973.

24. Ludwig, F. L., and R. L. Mancuso. User's Manual for the APRAC-1a Urban Diffusion Model Computer Program. Prepared for the Division of Meteorology, Environmental Protection Agency, under Contract CAPA-3-68(1-69) (NTIS PB 213091). Research Triangle Park, North Carolina 27711. September 1972.

25. Ludwig, F., et al. User's Manual for the APRAC-2 Emissions and Diffusion Model. Prepared by Stanford Research Institute, Menlo Park, California, for the U.S. Environmental Protection Agency, Region IX Office. 1977.

26. Monitoring and Analysis of Carbon Monoxide and Traffic Characteristics at Oakbrook. GCA Corporation, GCA/Technology Division, Bedford, Massachusetts. Prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina. Report No. EPA-450/3-74-058. November 1974.